**CHROMATE CONTENT BIAS VERSUS
OVERSPRAY PARTICLE SIZE IN THREE
AIRCRAFT PRIMER PAINTS**
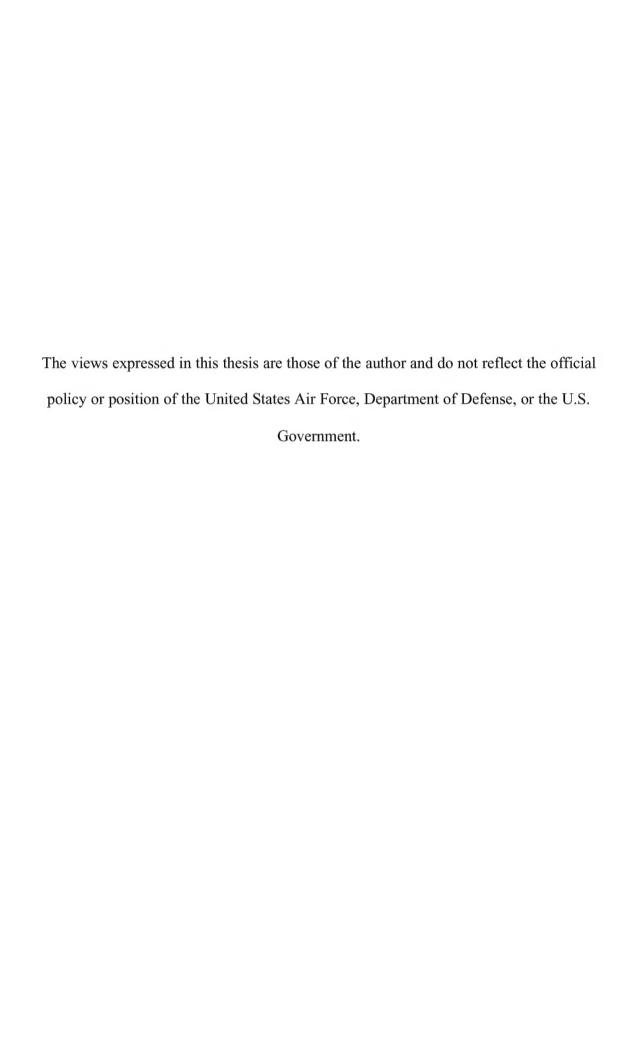
THESIS

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DEPARTMENT OF THE AIR FORCE
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AIRCRAFT PRIMER PAINTS

THESIS

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Abstract

The United States Air Force relies on the corrosion inhibiting properties of chromate-containing primer paints to protect the aluminum skin of its aircraft. Hexavalent chromium (Cr^{6+})—the ingredient responsible for the corrosion inhibiting characteristics of these primers—is a known human carcinogen. The concentration of Cr^{6+} in different particle sizes of paint overspray is important to understand health implications to painters as well as filtration efficiency. Previous research indicates disproportionately less Cr^{6+} content in smaller particles collected in the overspray of solvent-based epoxy-polyamide paint primers (MIL-P-2377G).

This research explores the possibility of a particle size bias in the Cr^{6+} content of three commonly used aircraft primers: solvent-based epoxy-polyamide, water-based epoxy-polyamide (MIL-PRF-85582C), and solvent-based polyurethane (TT-P-2760A). The mass ratio of air flow to paint flow (A/P ratio) was varied during initial atomization. Seven-stage cascade impactors collected overspray particles into distinct bins with particle size cutoff diameters ranging from 0.7 μm to 34.1 μm. The mass of the dry paint collected in each bin was determined and analyzed for Cr^{6+} with an Atomic Absorption Spectrometer.

In all three primers, smaller particles contained disproportionately less Cr^{6+} per mass of dry paint than larger particles. Particles with an aerodynamic diameter under 7 μm contained less Cr^{6+} per mass of dry paint as the particles became smaller. Particles less than 2.6 μm have a mean Cr^{6+} content of approximately one-third of the expected

value. The range of A/P ratios tested in this study had no effect on the Cr^{6+} content in the overspray.

CHROMATE CONTENT BIAS VERSUS OVERSPRAY PARTICLE SIZE IN THREE AIRCRAFT PRIMER PAINTS

I. Introduction

Air Force Primer Paint Overview

The United States Air Force (USAF) relies on the corrosion inhibiting properties of paint coating systems to protect its aircraft, which must endure extreme environmental conditions. These coating systems are typically comprised of a surface preparation, a primer coat, and topcoat paint. The primer coat, which is between the surface and the topcoat, provides an adhesive surface for the topcoat. Additionally, the primer contains additives that inhibit oxidation of the aircraft's aluminum skin. These additives are typically chromate (CrO_4^{2-})-containing compounds.

The most commonly used corrosion control additive in primers, strontium chromate ($SrCrO_4$), presents the greatest risk of cancer for aircraft painters (California Department of Health Services, 1992). The most commonly used military specifications (MIL-P-23377G, MIL-P-85582B, and MIL-P-87112) and federal specification (TT-P-2760A) that regulate primer paint designate $SrCrO_4$ or barium chromate as the default corrosion inhibitors (T.O. 1-1-8). Strontium chromate contains chromium in its hexavalent state (Cr^{6+}). Cr^{6+} is considered a carcinogen by most national and international health and medical agencies (International Agency for Research on Cancer (IARC), 1990).

The primary cancer risk associated with exposure to Cr^{6+} is through inhalation of Cr^{6+}-containing dusts, mists, and fumes. Most epidemiology studies that have focused on exposure of workers involved in the production of chromates and Cr^{6+}-containing

pigments show an excess risk of respiratory cancer. Similar studies that examine the risk of cancer for workers that use Cr^{6+}-containing compounds, such as spray painters, are relatively fewer in number and demonstrate a less definitive risk (Dalager *et al.*, 1980:25). It has been suggested that the type of aerosol generated in a process (e.g., liquid aerosols, mists, or dusts) is an important factor in determining the health risk of Cr^{6+} (Finley *et al.*, 1992:170).

A number of factors are important when characterizing the harmful effects of Cr^{6+} inhalation. As with any inhalation hazard, particle size distribution determines the how much material will deposit in various regions of the respiratory system. In general, smaller particles will deposit more deeply in the respiratory system and larger particles will deposit in the upper respiratory region primarily due to impaction, sedimentation, and interception (Schlesinger, 19XX:192). Furthermore, the determination of the percentage of Cr^{6+} in the particles that are of a size that is readily inhalable is important. Also, investigating any dependence of Cr^{6+} content on particle size is important since smaller particles tend to deposit more deeply into the respiratory system. The deeper a particle penetrates into the respiratory system, the longer the particle will remain in the system.

In the aircraft painting industry, workers are exposed to Cr^{6+} in the paint overspray created from the application of primer on the aircraft surface. The suspension of these Cr^{6+}-containing particles presents an inhalation exposure risk to the painters. Therefore, in order to determine the risk to the worker, the distribution of the Cr^{6+} over the range of particle sizes in the overspray must be characterized.

Thesis Objective

  This study follows previous work, which found that the larger particles contain disproportionately more Cr^{6+} than smaller particles in the overspray of military specification MIL-P-23377G primer, which is a solvent-based epoxy-polyamide primer paint hereinafter referred to as solvent EP primer. (Fox, 2000; Novy, 2001). The focus of this study is to quantify the Cr^{6+} distribution as a function of particle size for three commonly used Cr^{6+}-containing aircraft primer paints.

  The objectives of this study are to:

1) Quantify the Cr^{6+} content in the oversprays of solvent EP, military specification MIL-PRF-85582C (a water-based epoxy-polyamide primer paint hereinafter referred to as water EP primer), and federal specification TT-P-2760A primer paint (a solvent-based elastomeric, polyurethane primer paint hereinafter referred to as polyurethane primer), and

2) Observe whether the air-to-paint (A/P) ratio—a measure describing certain operating conditions of the spray gun—will influence the Cr^{6+} distribution in various particle sizes for the solvent EP, water EP, and polyurethane primer paint overspray.

II. Literature Review

Chromium

Chromium is a naturally occurring element commonly found in the earth's crust. It typically exists in the trivalent (Cr^{3+}), hexavalent (Cr^{6+}), or elemental (Cr) states, however, short-term intermediate states can be found including Cr^{2+}, Cr^{4+}, and Cr^{5+}. Chromium has been recognized as an important metal in a variety of industrial applications as well as an active component in a number of biological processes.

Due to its strong oxidative characteristics, Cr^{6+} is used in a wide range of industries, including chemical and metallurgical. Hexavalent chromium—a key component in stainless steel—can be found in the alloy to inhibit oxidation of the iron as well as the protective casing of "chrome-plated" steel compounds. Similarly, Cr^{6-} compounds are popular in the painting industry because of their corrosion inhibiting behavior. Additionally, Cr^{6+} is universally used as a pigment in paint, ink, and plastic production industries.

Besides its industrial uses, chromium plays an important role in a few key metabolic pathways in the human body. Cr^{3+} is an essential micronutrient for humans. Although only very small quantities are needed, Cr^{3+} is necessary for the metabolism of glucose through the potentiation of insulin (Felter, 1997: 43). The National Research Center recommends a minimum Established Safe and Adequate Daily Dietary Intake of 50-200 µg (National Center for Complementary and Alternative Medicines, 2000). Although the beneficial aspects of Cr^{3+} are well documented, more attention is given to the deleterious health effects of Cr^{6+}, which are discussed in the following section.

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Health Effects of Chromate Exposure

The primary pathways of Cr^{6+} exposure are inhalation, ingestion, and dermal contact of chromate-containing compounds. Ingestion is a more prevalent pathway of exposure for children, although workers have been found to ingest Cr^{6+} due to poor hygiene at meal and smoking breaks. Dermal contact is generally associated with localized, non-cancerous health effects. The majority of epidemiology studies performed on workplace exposure to Cr^{6+} focuses on the excess cancer risks from inhalation, which is also the pathway of greatest concern.

The source of inhalable Cr^{6+}, predominately found in the form of mists, dusts, and fumes, varies depending on the industrial use of the chromate-containing substance. In spraying operations, fine mists are created during the atomization of the coating liquid. Although respiratory protection and ventilation controls are frequently required in these operations, workers still risk inhalation exposure, as these controls sometimes fail or are overwhelmed. Similarly, in plating operations, chromic acid mist presents an inhalation hazard created by vapor that diffuses to the surface of drip tanks and carries liquid chromic acid particles into the air. Welding is another commonly cited activity that is associated with Cr^{6+} inhalation. In this case, the Cr^{6+} exposure results from the intense heat applied to the stainless steel or chromium-coated material, thus changing the solid metal into a Cr^{6+} fume (CDHS, 1992).

As previously noted, Cr^{6+} is widely recognized for its carcinogenic potential. IARC sites numerous studies that show evidence for carcinogenicity of chromate-containing compounds, including strontium chromate, in experimental animals. In a study of the carcinogenicity potential of chromium-containing materials, Levy *et al.*

found that strontium chromate and, to a lesser extent, zinc chromate caused bronchial carcinomas in rat lungs (Levy *et al.*, 1986: 243). In this study, an intrabronchial implantation system was used to dose the rats with the test material in pellet form.

The IARC and other agencies also conclude that Cr^{6+} compounds are carcinogenic to humans based, in part, on several epidemiology studies of workers in the chromate production, chromate pigment production, and chromium plating industries (IARC, 1997) which show an elevated risk of lung cancer.. In an early study, Mancuso (1975) reported an elevated risk of lung cancer in chromate production workers. However, this study did not record the smoking habits of the study group. Therefore, smoking—a leading cause of bronchial carcinomas—could not be discounted as a possible confounding factor. Gibb *et al.* (2000) repeated this effort in a cohort study of 2357 workers in the chromate production industry. With improved background history of the study subjects, Gibb *et al.* were able to determine that the excess risk of lung cancer was not confounded by the prevalence of smoking among workers.

As compared to the findings in the aforementioned industries, the relatively few studies that focused on the carcinogenicity of chromium in the painting industry have reported conflicting data. In a study of 4760 deceased spray painters from ten automobile assembly plants that used paints with chromate pigments, no statistically significant proportionate mortality ratio (PMR) (as compared to expected deaths in the general population) was found at any of the locations (Chiazze *et al.*, 1980:526). Additionally, a cohort study of 2429 aerospace workers, found no link to increased risk of respiratory cancer among painters with chromate containing paint exposure (Alexander *et al.*, 1996:1257). However, in a study of 202 deaths among over 40,000 workers employed at

two government-owned aircraft maintenance bases where zinc chromate was used in painting operations, a statistically significant elevation of the proportionate cancer mortality ratio (PCMR) was noted at one base (Dalager *et al*., 1980:28). No information was available on the smoking status of the workers. Consequently, the authors of the study suggested that smoking could not be discounted as a possible confounding factor given the higher prevalence of smoking among painters as compared to the general population. There is not a clear link between lung cancer and spray painters exposed to Cr^{6+} due to the inconsistency of the studies.

Particle Deposition in the Lung

Given that pulmonary carcinoma is the primary adverse health effect from Cr^{6+} exposure, the distribution of Cr^{6+}–containing particles in the respiratory system is of interest. The size of the inhaled particle affects the location that particle will deposit in the lungs. Specifically, it is the aerodynamic diameter (d_{ae}) of a particle or the mass median aerodynamic diameter (MMAD) of an aerosol (i.e., the d_{ae} at which half of the mass of an aerosol distribution is less than) that is important in determining the characteristics of the deposition of particles with geometric diameters greater than 0.5 μm (Schlesinger, 1995). Schlesinger lists five main mechanisms responsible for particle deposition in the respiratory system: impaction, sedimentation, Brownian diffusion, electrostatic precipitation, and interception (Schlesinger, 19xx:192). Each of these mechanisms will dominate in different regions of the respiratory system for different sized particles, though impaction is responsible for the majority of deposition in the conductive zone—from the nasal passage or mouth to the terminal bronchioles—for

particles having MMAD greater than 0.5 μm. A typical deposition pattern for an adult

male is shown in Figure 1 (Godish, 1991:156).
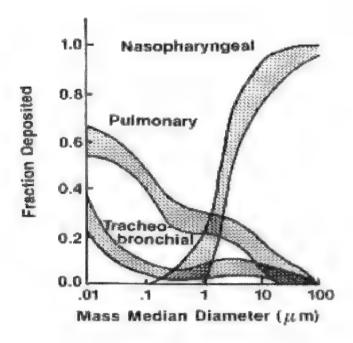
Figure 1. Fractional Deposition of Particles (Task Group on Lung Dynamics, 1966)

USAF Primer Paint

Solvent EP, water EP, and polyurethane primers are the most commonly used

primer paints on USAF aircraft surfaces. While the specifications corresponding to all

three of primers list $SrCrO_4$ as the default corrosion-inhibiting additive, the chemical and

physical properties of these primers differ. This section gives a general description and

chromium content of each type of primer used in this study.

Solvent-Based Epoxy-Polyamide.

Solvent EP primer is a two-component (base and catalyst) epoxy-polyamide

primer. This solvent-borne primer is a low volatile organic compound (VOC). Low

VOC, as defined by the Environmental Protection Agency, is a paint that has a VOC

content less than 340 grams per liter at application. The solvent EP primer is the most frequently used primer paint in the Air Force and is known for its solvent and chemical resistance. The mix ratio of solvent EP primer is 3 parts base to 1 part catalyst. The base component contains 25% $SrCrO_4$ by weight (w/w) according to the Material Safety Data Sheet (MSDS). Accounting for the mix ratio, densities of components, and mass fraction of Cr^{6+} in $SrCrO_4$, the expected Cr^{6+} content (as Cr^{6+}) in the mixed paint is 5.2% (w/w). Since the mixed primer is 72.72% non-volatiles (w/w), the expected Cr^{6+} content in the non-volatile fraction of this primer is 7.13% (w/w). Sample calculations of the expected chromium content in mixed paints are given in Appendix A.

Water EP.

The water-reducible epoxy-polyamide primer is sometimes substituted as a lower VOC content alternative to the solvent EP primer. The base-to-catalyst ratio is specified as 2:1, with a 4.1-part water reduction (*i.e.*, the mixed paint is—by volume—about 58% water, 28% base component, and 14% catalyst component). Although the base component is 30% $SrCrO_4$ (w/w) according to the MSDS, the actual chromium content in the mixed primer paint is only 2.54% (w/w). Due to the large water content, the non-volatile fraction of the paint comprises only 34.08% (w/w) of the primer, yielding an expected Cr^{6+} content in the non-volatile fraction of the paint at 7.46% (w/w).

Polyurethane.

Federal specification TT-P-2760A is a two-component, solvent-borne polyurethane primer. This elastomeric, low VOC primer has excellent flexibility characteristics. This primer paint is composed of equal parts (by volume) of base and catalyst components. Accounting for the different densities of the components, the

chromium content in the mixed primer is 3.03% (w/w). Since the mixed primer is

70.84% solids (w/w), the expected Cr^{6+} content in the solids fraction of this primer is

4.28% (w/w).

Deft, Inc manufactured all three primer paints investigated in this study. A

summary of the primer specifications and chromium content is listed in Table 1. (A more

detailed listing of primer component specifications is given in excerpts from the product

data sheets and MSDS, which can be found in Appendices B, C, and D.)

Table 1. Summary of Primer Product Codes and Chromium Content

	Solvent EP	Water EP	Polyurethane
Military or Federal Specification	MIL-P-23377G Type I, Class C	MIL-PRF-85582C Type I, Class C2	TT-P-2760A Type I, Class C
Manufacture (Deft®) Product Code	02-Y-40	44-GN-72	09-Y-2
Basic Description	Solvent-based, epoxy polyamide	Water-reducible, epoxy polyamide	Solvent-based, elastomeric polyurethane
Batch Numbers Tested	Base: 46517 Catalyst: 46518	Base: 45699 Catalyst: 45700	Base: 45526 Catalyst: 45527
Mfg Dates	July 2001	April 2001	March 2001
$SrCrO_4$ Content (w/w) in Base Component	25%	30%	20%
Cr^{6+} Content (w/w) in Mixed Primer (as specified)	5.19%	2.54%	3.03%
Percent Non-Volatiles in Mixed Primer	73.10%	34.08%	70.84%
Cr^{6+} Content (w/w) in Dry Primer	7.13%	7.46%	4.28%

Regulatory Exposure Limits

In the United States, the Occupational Safety and Health Administration (OSHA) is the government agency charged with establishing regulations to protect workers from hazardous exposure to chemicals. OSHA accomplishes this primarily through the establishment of permissible exposure limits (PELs). These limits are determined after a thorough review of all relevant scientific data from industry, government, and the research communities. The PEL, a ceiling that can never be exceeded at any time, for chromate is 0.1 mg/m^3 (as CrO_3) (29 CFR 1910.1000, Table Z-2). In 1993, however, OSHA was petitioned by the Oil, Chemical, and Atomic Workers International Union (OCAW) and Public Citizen's Health Research Group (HRG) for an emergency temporary standard (ETS) to reduce limits to occupational exposures to Cr^{6+}. Although the request for an ETS was denied, it prompted OSHA to offer a proposed rule which would replace the current PEL with an eight-hour, time-weighted average (TWA) of 0.0005 mg Cr^{6+}/m^3 (OSHA, 1996).

This proposed limit is identical to the current eight-hour Threshold Limit Value (TLV-TWA) set by the American Congress of Governmental Industrial Hygienists (ACGIH). ACGIH is a private organization of professionals that establishes exposure limits intended to protect workers from adverse health effects. Although limits set by ACGIH are not legally enforceable, OSHA and industry often reference ACGIH guidelines. Like OSHA, ACGIH relies on the most relevant scientific data on the health effects of exposure levels to establish a limit for a chemical. Much of the information regarding the exposure to Cr^{6+}-containing compounds is based on the chromium

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production, chromium-pigment production, and chromium plating industries (Finley *et al.*, 1992:170).

Particle Kinetics

In order to understand the distribution of chromate in the overspray of aircraft paint, it is necessary to characterize the nature of the overspray. A brief review of the atomization process that the liquid paint must undergo reveals a number of parameters that may affect the mean particle size, the size distribution of the paint particles, and the bias in the Cr^{6+} content over the range of particle sizes. This section describes the atomization process as well as some of the key parameters relevant to spray painting.

Atomization Overview.

In general, the atomization process of spray painting, like all types of atomization, involves the disintegration of a liquid into drops (*i.e.*, the dispersed phase) suspended in a gaseous media (*i.e.,* the continuous phase) due to an acting force (Bayvel and Orzechowski, 1993:37). As the liquid stream of paint emerges from the nozzle of the gun, external forces, mostly from an air stream applied at the nozzle exit, and turbulent properties of the fluid begin to break the jet into thin ligaments, which eventually further disintegrate into drops. Because of this progression of droplet formation, many characteristics of the spray, such as drop size distribution and drop velocity, are functions of both space and time (Lefebvre, 1989:2). Lefebvre notes that these characteristics are influenced by many parameters including the geometry of the spray gun and nozzle, the properties of the air into which the paint is discharged, and the physical properties of the liquid paint (1989:2).

Paint Atomization Device.

As sprays can be produced by a number of different atomization processes, the atomization devices will differ in geometry, operational design, and operational settings to produce sprays with various characteristics. In the case of spray painting, the nozzle and air cap of the spray gun can be classified as an airblast atomizer. In this type of atomizer, the paint is discharged through the nozzle into a thin stream. The air cap, which is mounted at the end of the paint nozzle, has two protrusions on the outer edge
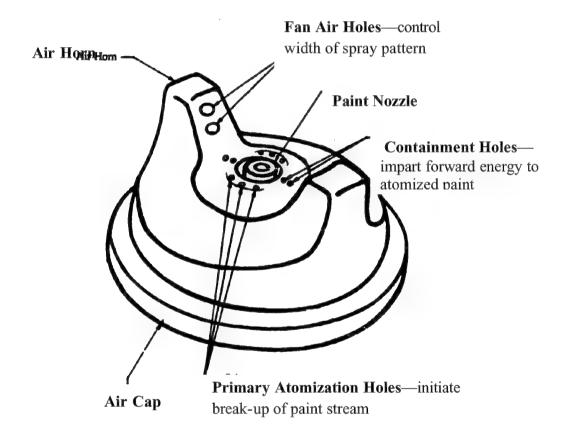
Figure 2. Illustration of Typical Air Cap (Kwok, 1991)

called air horns. Closer to the center of the cap, two sets of holes can be found from which compressed air jets are formed. The closest sets of jets, the primary atomization holes, are on opposing sides of the nozzle as shown in Figure 2. The primary atomization

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holes release high volume jets of air, which shear the liquid stream to begin atomization. The paint stream is broken into thinner streams that move in an outward direction as the energy from the air has changed the original vector of the paint stream. The outer pairs of holes at the base of each air horn are the containment holes. The air from the containment holes will send the particles in an elongated elliptical pattern towards the target (Kwok, 1991:5). The adjustable volume of air released from the fan holes serves as an additional control on the pattern width of the paint. The number, layout, and size of atomization and containment holes will vary in different air caps.

Liquid Properties.

The properties of the paint—primarily, density, surface tension, and viscosity—will also determine particle size distribution. Theoretically, mass flow rate will increase proportionally with the square root of the liquid density. However, the change in density of a liquid will almost always result in a change in the other properties of a liquid which also influence particle size distribution (Lefebvre, 1989:11).

Surface tension is related to the force with which the liquid will resist the change in surface area (*i.e.*, the formation of new surface due to atomization). Thus, the minimum energy required to atomize a given volume of liquid is equal to the surface tension multiplied by the ratio of atomized surface area to original surface area (Lefebvre, 1989:11). Given the difficulty in quantifying the increase in surface area, the effects of viscosity on flow and spray characteristics may be more beneficial to monitor.

The influence of paint viscosity on particle distribution can be seen prior to the atomization process. A more viscous liquid will prevent the development of instabilities in the jet considering an increase in viscosity will lower the Reynolds number.

Therefore, with a more viscous liquid, the disintegration of the liquid jet will occur at lower energy farther from the nozzle, resulting in larger droplet diameters (Lefebvre, 1989:11). Furthermore, the liquid flow rate through the nozzle will usually decrease as viscosity increases. However, the diameter of the droplets produced by airblast atomizers does not vary much due to a change in viscosity (Lefebvre, 1989:14). Lefebvre claims that the influence of viscosity on drop sizes is more pronounced in pressure atomizers that have a higher liquid velocity relative to airblast atomizers. However, experimental evidence contradicts this logic. By increasing viscosity of the paint from 57 centistokes (measure of a materials kinematic viscosity equal to mm^2/s) to 106 centistokes, the MMAD increased slightly from 38 μm to 46 μm (Kwok, 1991:192). Although an increase in pressure caused an increase in average particle size, Kwok found that the shape of the distribution of the collected overspray was not influenced by a change in viscosity.

Air-to-Paint Ratio.

Given the liquid properties of a paint and design parameters of a spray gun, only the operational settings are likely to affect the atomization quality of the paint. Of the operational settings, the ratio of air mass flow to paint mass flow through the gun has the greatest influence on the degree of atomization (Kwok, 1991; Carlton and Flynn, 1997). Kwok observed that increasing the A/P ratio resulted in smaller particles as well as more overspray (*i.e.*, lower transfer efficiency). Since increasing the A/P ratio changes the magnitude of forces responsible for atomization, it may influence the Cr^{6+} content of paint particles as well. It is worth noting that while increasing the A/P ratio will always provide for more atomization (*i.e.*, smaller particles), the effect that this parameter has on

transfer efficiency—defined as the percentage of mass of paint sprayed that remains on target—depends on other factors. Since transfer efficiency is a function of the Stokes number, which is proportional to the square of the particle diameter times the particle's velocity, the change in the velocity of the particle is important to determine if the particle will impact the target (Kwok, 1991).

Secondary Atomization.

With the basic theory of atomization described above, it is important to mention the concept of secondary atomization. An understanding of the process by which larger particles, created from the initial atomization, are subsequently atomized into smaller particles is helpful in order to gain insight about possible explanations of a bias in the Cr^{6+} content toward larger overspray particles. The likelihood of a suspended liquid drop breaking up in air largely depends on the Weber number of that drop exceeding its critical Weber number (We>We*) (Bayvel and Orzechowski, 1993:70; Lefebvre, 1989).

$$We* = \frac{8}{C_D} \qquad (1)$$

where

C_D = drag coefficient of the drop,

and

$$We = \frac{\rho_L V_L^2 D}{\sigma} \qquad (2)$$

where

ρ = liquid density
V_L = liquid velocity in outlet orifice
D = drop diameter
σ = surface tension of liquid

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Criteria other than the critical Weber number may also determine the degree of secondary atomization, such as the type of load acting on the initial drop, liquid viscosity, time of disintegration, and drop diameter (Bayvel and Orzechowski, 1993: 74).

In general, a few different mechanisms have been observed that describes the disintegration of a drop. The three most common mechanisms that describe the formation of smaller drops from a larger drop are the "parachute"-type disintegration mechanism, the chaotic mechanism, and the shear mechanism. The major difference in the various processes is the orientation of the deformation of the spherical drop. A drop that is flattened, forming an oblate ellipsoid, may stretch to the point to which it forms a ring-like shape that disintegrates into several smaller drops (a.k.a. "parachute"-type disintegration or bag mechanism). Bayvel and Orzechowski describe a particular scenario involving several parachutes developing simultaneously on a single drop—the chaotic mechanism. A drop, which becomes elongated into a cigar-shape, may develop into ligaments from which smaller drops are sheared—the shear mechanism. Additionally, local deformations may develop on a drop that result in the occurrence of the shear mechanism or the burst mechanism—a situation where "shear-type" disintegration proceeds very rapidly (Bayvel and Orzechowski, 1993:72; Lefebvre, 1989; 30).

Understanding possible mechanisms responsible for the atomization of particles may help explain the disproportionate decrease in the Cr^{6+} content in smaller particles in the overspray. Varying the A/P ratio in this study should vary the forces involved in secondary atomization. The effect of these forces on the Cr^{6+} content in a given particle

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size range may help explain possible mechanisms responsible for the bias in Cr^{6+} as a function of particle size.

Particle Collection

Since part of the motivation behind this research is to characterize the relative quantity of Cr^{6+} in various sizes of paint particles, it was desirable to select a method of particle collection that would separate a particle stream according to size in a manner similar to the mechanism of particle deposition in the human respiratory system. While many different collection techniques that rely on mechanisms such as gravitational settling and thermal precipitation have been used to collect and analyze particle distributions, most collection devices are based on the mechanism of inertial impaction (Marple *et al.*, 1993:206). Inertial impaction—not simply particle size—is the most important factor determining particle deposition. Not only is impaction responsible for a particle depositing on the target surface of painting operations, impaction is responsible for most particle deposition is the lungs. Impactors (single- or multi-stage) have become the standard collection instrument used in the determination of particle distributions of paint overspray (Kwok, 1991; Chan *et al.*, 1986; Ackley, 1980).

The principle of inertial classification is based on categorizing particles based on their inertia. Basically, a particular flow condition is set so that a particle entering a collection device will either possess enough inertia so that it escapes the trajectory of the gas streamline or possess too little inertia so that it remains in the gas streamline. Particles that break free of the gas flow will continue in a new trajectory until they impact on a collection plate.

Cascade impactors, which are used as the particle collection device in this study, contain multiple numbers of collection plates called stages. Each subsequent stage in these impactors has smaller inlet jets that create progressively greater velocities of the particle-laden gas stream, which allow for impaction of smaller particles that possessed less inertia in the previous stage. (A schematic drawing of a typical cascade impactor is shown in Figure 3. As Figure 3 illustrates, a stage is consists of the area from the inlet nozzle to the impaction plate on which the nozzle flow impinges (Hinds, 1982:120)).
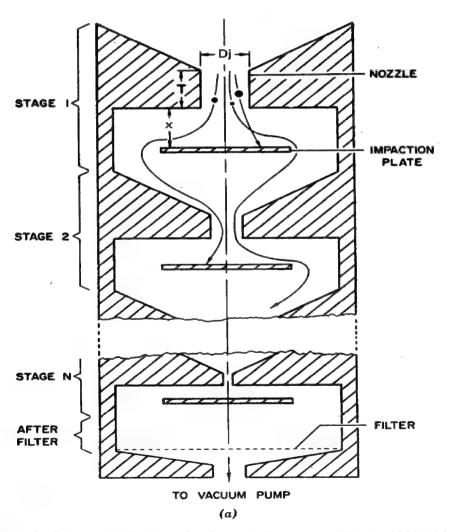
Figure 3. Schematic Design of a Cascade Impactor (Hinds, 1982:120)

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Each stage of the cascade impactor collects particles in a specific size range based on aerodynamic diameter. The nominal measurement of that stage is usually referred to as the effective cutoff diameter (ECD_{50}) or, simply, cutoff size. In operation, the
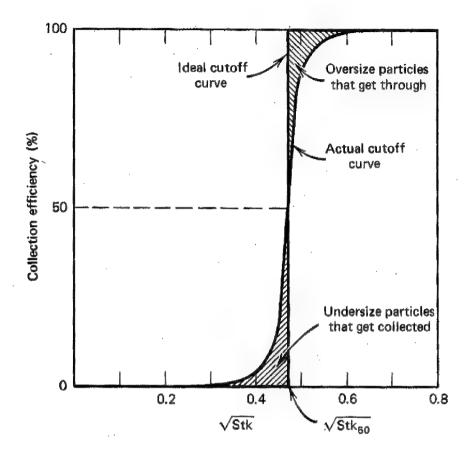
Figure 4. Actual and Ideal Impactor Cutoff Curves (Hinds, 1982:117)

aerodynamic diameter of the particles collected on a particular stage is assumed to be larger than the ECD_{50} of that stage and smaller than the ECD_{50} of the previous stage (Lehtimaki and Willeke, 1993:117). The ECD_{50} of a stage is defined by the aerodynamic diameter of a particle that is captured with 50% efficiency by that stage—in other words, the lower cutoff size. As displayed by Figure 4, it can be assumed that, for this particle size, the "mass of particles larger than the cutoff size that get through (upper shaded area)

equals the mass of particles below the cutoff size that are collected (lower shaded area)." (Hinds, 1982:117).

As shown in Figure 4, the cutoff size is often recorded in terms of the square root of a dimensionless parameter, the Stokes number (*Stk*) defined as:

$$\sqrt{Stk} = \sqrt{\frac{\rho_p C_c d_p^2 U}{9 \mu W}}$$

(3)

where

ρ_p = particle density
Cc = slip correction
U = average air velocity at the nozzle exit (=$Q/\pi(W/2)^2$) for a round nozzle
d_p = particle diameter
μ = air dynamic viscosity
W = nozzle diameter
Q = volumetric flow rate through the nozzle

To calculate the cutoff sizes for each stage rearrange the equation as shown:

$$d_{50} = \sqrt{\frac{9\eta W}{\rho_p C_c U}} \sqrt{Stk_{50}}$$

(4)

where d_{50} = ECD$_{50}$ for any given stage (Marple *et al.*, 1993:207-11).

In this study, the ECD$_{50}$ was calculated for each stage based on the following version of equation (4):

$$ECD_{50} = \sqrt{\frac{(.495)(\mu)(D_j^3)(n)(\pi)}{(Q)(\rho_p)}}$$

(5)

where   0.495 = Stokes number for round jets (Hinds, 1982:118)
             D_j^3 = jet diameter in cm
             n   = number of jets on the stage
             π = 3.1416
             Q   = volumetric flow in cm^3/sec
             ρ_p = partial density for aerodynamic equivalent = 1 g/cm^3
             μ = viscosity of air at 22° C = 1.83 x 10^{-4} g/cm-sec

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This equation is equivalent to equation (4), but re-arranged in terms of volumetric air flow, Q. Also, the nozzle width, W, from equation (4) is replaced by the term $(D_j^3)(n)$ in equation (5).

Paint Overspray Distribution

Several studies have sought to characterize the particle size distribution of various types of paint. Although the overspray of different paints produce different particle size distributions, significant reductions in the MMADs of the overspray were reported with increasing atomization pressures. Chan *et al*. (1986) used an air spray gun to generate overspray of high-solids acrylic base coat and clear coat. Spraying with atomization pressures of 30 to 65 psig, they measured the MMAD of the overspray at 6.5 to 4.5 μm, respectively. Another study by Ackley (1980) found that lacquer and enamel paint overspray generated from air-blasting had an average MMAD of 6 μm. Kwok (1991) found that acrylic enamel paint produces an overspray with MMADs of 30 and 52 μm when sprayed with atomization pressures of 68 and 20 psig, respectively (Kwok, 1991).

Previous Overspray Exposure Research

While research has been done to characterize the distribution of the particles generated from spray painting, little research has explored the chemical composition of the particles within that distribution of particles. Furthermore, many studies have sought to estimate the exposure of workers to paint overspray (Brosseau *et al*., 1992; Carlton and Flynn, 1997). In these studies, however, the effort was focused on the concentration of particles, not the concentration of a specific chemical, in the worker's breathing zone. It is generally assumed that the exposure hazard is directly proportional to the overall distribution of particles collected without regard to any variation in the chemical

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composition of the various particle sizes. Without information available on the chemical composition of different sized particles, it is often assumed that the particles in the overspray are identical in composition to the bulk analysis of the liquid paint.

Few studies have investigated the possible non-uniformity of chemical composition throughout a particle distribution of paint overspray. D'Arcy and Chan investigated the differences between the distribution of overspray aerosol and the distributions of various inorganic species used as pigments or luster enhancers in six different high-solids automotive primer paint (D'Arcy and Chan, 1990). After collecting overspray aerosol using seven-stage cascade impactors, MMADs of the overspray were reported between 2.9 to 9.7 µm. Atomic absorption spectrometry (AAS) was used to determine the mass distribution of aluminum and iron in the overspray collected on the impactor stages. In all samples, the overall MMAD of iron was less than or equal to the MMAD of the total overspray aerosol. However, most aluminum distributions were found to have a higher MMAD than that of the overspray aerosol. They concluded, "using the size distribution of the total overspray aerosol to estimate the respiratory tract penetration of an inorganic species can produce estimates which differ from those based on the chemical distribution of the species," (D'Arcy and Chan, 1990:3877). These results demonstrate the importance of knowing the chemical composition of the overspray particles throughout the entire size distribution to evaluate the true exposure of Cr^{6+} to the painter.

Cr^{6+} Content Bias

A previous study explored the Cr^{6+} content (μg Cr/mg dry paint) in overspray particles as a function of aerodynamic diameter using solvent-based epoxy-polyamide primer paint (Fox, 2000). His data revealed a statistically significant difference in the Cr^{6+} content in particles with an aerodynamic diameter (d_{ae}) less than 2.5 μm

$(18 \dfrac{\mu g\, of\, Cr}{mg\, of\ drypaint})$ as compared to particles with a d_{ae} larger than 2.5 μm

$(70 \dfrac{\mu g\, of\, Cr}{mg\, of\ drypaint})$. Based on the likely location of deposition of particles with a d_{ae}

greater than 2.5 μm, this finding suggests that a greater mass fraction of Cr^{6+} is deposited in the upper respiratory tract than reaches the respiratory zone.

Novy also studied solvent EP primer, using the same military specification paint from two different manufacturers (Deft Inc., Irvine, CA and PRC-DeSoto International, Mojave, CA) (Novy, 2001). Novy was able to demonstrate a more detailed bias in Cr^{6+} content as a function of aerodynamic particle size. Figure 5 shows the Cr^{6+} content in dry solvent EP plotted as a function of the impaction stage ECD_{50}. This study will focus on the Cr^{6+} content in the particles of solvent EP as well as two other primers not previously investigated for Cr^{6+} bias.
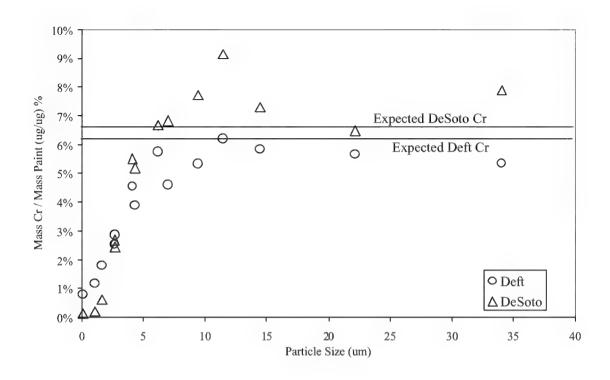
**Figure 5. Comparison of Mass Cr per Mass Dry Paint by Manufacturer
(Novy, 2001)**

III. Methodology

Overview

This chapter describes the equipment and methods used to generate, collect, and analyze the Cr^{6+} content by particle size for three different types of primer paints. Since this study also investigates the possible influence of A/P ratio on Cr^{6+} content of paint particles, the spray painting operation parameters are discussed.

Painting Operation

All painting operations were conducted in a paint booth at the Coatings Technology Integration Office (CTIO) at Wright-Patterson Air Force Base, Ohio. The dimensions of this environmentally controlled booth are 10' wide by 14' long by 9' high. Temperature and humidity were maintained at 24 degrees Celsius (± 4 degrees) and 8% (± 6%), respectively, for each sampling event. The ventilation inside the booth was set at 100 linear feet per minute—the minimum ventilation rate required by OSHA in paint spraying operations.

<u>Recorded Data.</u>

Thirty-four painting runs were performed: eight with solvent EP, sixteen with water EP, and ten with polyurethane. Each of the paints was prepared in accordance with the respective product data sheets. A summary of the mixing ratios and selected specifications of these paints is given in Table 2.

Table 2. Primer Preparation Specifications (Deft, 2000)

Primer Type	Mix Ratio			Collection Runs	Viscosity Test (Ford #4 cup)
	Base	Catalyst	Water		
Solvent-based, epoxy polyamide	75%	25%	0%	8	20-40 sec
Water-reducible, epoxy polyamide	28%	14%	58%	16	18-22 sec
Solvent-based, elastomeric polyurethane	50%	50%	0%	10	14-24 sec

To generate the paint overspray, a DeVilbiss model JGHV-531 HVLP spray gun, fitted with a DeVilbiss model 46MP air cap, was used. A two-quart, pressure fed paint supply cup was attached to the spray gun. After the paint was prepared, the viscosity of the primer was tested using a Ford #4 cup. Once the viscosity test yielded results within the specifications given in Table 2, the primer was loaded into the paint supply cup. After the spray pattern was checked and the desired nozzle pressure was set, the spray conditions were held constant throughout the paint run.

A/P Ratios.

This study examines the effects on the Cr^{6+} content among different overspray particle sizes by varying one of the operational parameters of spray painting—the A/P ratio. The nozzle pressure was adjusted on different paint runs so that each of the three types of primers would be tested at two different A/P ratios. A higher A/P ratio was achieved by increasing pressure at the nozzle of the air cap (thus, increasing the air mass flow rate), while maintaining the same pressure to the supply cup (thus, minimizing changes to the paint flow rate). Using calibration data from the gun manufacturer, the

nozzle pressure can be used to estimate an air mass flow rate. Paint mass flow rates were calculated from the measured mass of paint used and the elapsed spray time of each run.

Pressure Settings.

For each of the paints, multiple sampling events were conducted at both a high A/P ratio and a low A/P ratio. Adjusting the wall pressure, which controlled the nozzle pressure, altered this ratio. However, the nozzle pressures were held constant for all runs within each category (i.e., high A/P ratio or low A/P ratio). The pressure in the supply cup (*i.e.*, pot pressure) remained at 14 psig for all sampling events. The pressure settings for all sampling events are documented in Table 3.

Table 3. Pressure Settings and A/P Ratios

| Paint Type | High or Low A/P | Number of Sample Runs | Pressure (psig) | | Air Mass Flow Rate (g/s) | Avg. Paint Mass Flow Rate (g/s) | Avg. A/P Ratio |
			Pot	Nozzle			
Solvent EP	Low	4	14	2.5	5.59	0.76	7.4
	High	4	14	8.0	11.0	0.88	12
Water EP	Low	10	14	7.0	9.92	1.16	8.8
	High	6	14	9.0	11.9	1.39	9.9
Polyurethane	Low	6	14	4.0	7.26	0.72	10
	High	4	14	8.0	11.0	0.69	16

The nozzle and pot pressures were established based on recommendations from painting technicians and guidelines from the primer product data sheets. As suggested by the conventional definition of HVLP, the nozzle pressure should be held under 10 psig. Product data sheets recommend a minimum of seven psig to establish enough atomization for an acceptable spray, although lower settings are commonly used in the field. The determination of an acceptable spray was based on qualitative assessment of experienced technicians.

Paint Mass Flow Rate.

After calculating the air mass flow rate, the A/P ratio can be determined by estimating the paint mass flow rate. The rate of paint flow was determined by two separate methods. In one measurement, the air jets that atomize the paint after exiting the nozzle were shut off. Closing these jets eliminated the source of atomization air without affecting the source of air used to pressurize the paint pot. A small mixing cup was used to collect and weigh approximately 30 mL of paint. The time needed to fill the test cup was used to calculate a mass flow rate.

The other method of testing the paint mass flow rate was conducted by measuring the net mass of the paint sprayed during the sampling event. The mass of paint sprayed was determined by recording the pre-weights and post-weights of the gun, pot, and connected hoses. Dividing the mass of the paint used by the recorded elapsed spray time provides the paint mass flow rate.

The latter method of estimating the paint mass flow rate was used to determine the A/P ratio since it accounts for possible variations in the paint flow rate during sample collection. A difference in the apparent density of particles in the overspray was visually observed towards the end of most sampling events. The former method was used as a quality control check. The average paint mass flow rate for each nozzle pressure is displayed in Table 3.

Background Runs.

In addition to the thirty-four painting runs, three sampling runs were conducted without any painting operations. These runs were performed to assess the background concentration of Cr^{6+} in the paint booth. The collection procedures for these events were

identical to all other sampling events with the exception of paint spraying. The average mass of Cr^{6-} collected on each stage during the background runs was subtracted from the appropriate stage of each paint run to ensure that the Cr^{6-} found on a stage of a paint run was from overspray particles.

Overspray Collection

To generate the paint overspray, the HVLP gun was aimed at a cardboard target and the overspray was allowed to draft toward the cascade impactors. This 15"x15" target was placed perpendicular to the direction of paint flow, eight inches from the tip of the gun's nozzle as depicted in Figure 6. Furthermore, the centerline of the paint stream
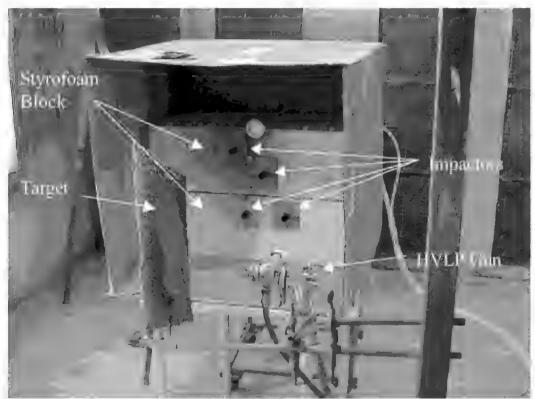

Figure 6. HVLP Spray Paint Gun with Sample Collection Set-up

from the gun to the target was 12" from the front edge of the cardboard enclosure that

contained the sample collection equipment. The enclosure was used to slow the velocity

of the overspray particles, thus increasing the number of particles collected. Booth

ventilation directed the overspray toward the cardboard enclosure located downdraft of

the HVLP gun. The face of the enclosure was 27" wide by 25" high. The face of the

block was recessed 13.5" from the edge of the enclosure—25.5" from the centerline of

the paint stream leaving the HVLP gun. Four cascade impactors (manufactured by In-

Tox Products) were used for overspray collection—two large-particle size range

impactors and two small-particle size range impactors. The placement of the impactors is
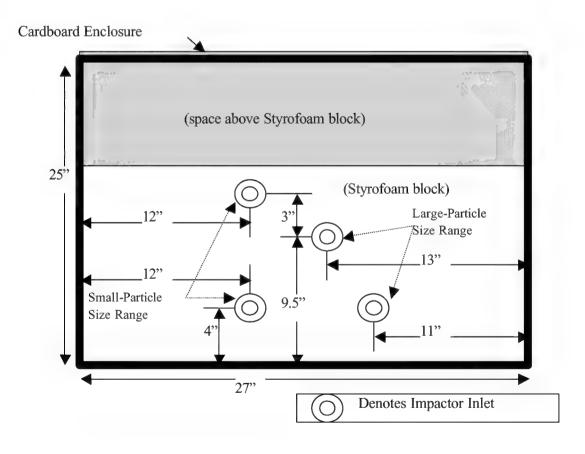
shown in Figure 7.

Figure 7. Impactor Layout (Not to Scale)

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The flow rate through the impactors was calibrated prior to the start of the sampling run. After each sampling event, the calibrations were checked. All post-calibration air flow readings were within 1% of the pre-calibrations. All calibrations were performed using a Gilibrator Airflow Calibration System #800286 with a high-flow bubble chamber.

After the impactors were calibrated, the trigger on the HVLP gun was held to a fully open position with a plastic zip tie for the duration of the sampling period. The durations of the sampling events varied from approximately 6 to 30 min. These times varied mostly due to the varying volumes (640 to 1000 mL) used during different painting runs. The volume of paint was varied to optimize sample collection without overloading the impactors.

Particle Size Ranges.

Four seven-stage cascade impactors were used to collect primer overspray particles and separate them into discrete size ranges (see Tables 4 and 5) based on their aerodynamic diameter. The ECD_{50} was calculated for each stage based on equation (5). In equation (5), the volumetric air flow rate through the impactors is the only variable able to affect the ECD_{50} of a stage. For this reason, the air flow rate was calibrated for each impactor to establish the ECD_{50} values. The large-particle size range impactors were calibrated at 8.000 (+/- 0.050) L/min; while, the small-particle size range impactors were set with a flow rate of 18.00 (+/- 0.10) L/min. The calculated ECD_{50} values at the designed flow rates for the impactors used in this study are given in Tables 4 and 5.

Table 4. Small Particle Size Range Impactor (18 L/min)

Stage #	1	2	3	4	5	6	7
Number of Jets per Stage	1	2	3	4	6	9	12
Average Jet Diameter (cm)	1.1125	0.0635	0.4003	0.2636	0.1679	0.1082	0.07315
ECD_{50} (μm) (18 L/min)	11.4	7.0	4.3	2.6	1.6	1.0	0.7
Particle Size Range of Stage	>11.4	7.0 to 11.4	4.3 to 7.0	2.6 to 4.3	1.6 to 2.6	1.0 to 1.6	0.7 to 1.0

Table 5. Large Particle Size Range Impactor (8 L/min)

Stage #	1	2	3	4	5	6	7
Number of Jets per Stage	1	1	2	2	3	4	6
Average Jet Diameter (cm)	1.7582	1.3208	0.7884	0.5636	0.3914	0.2692	0.1788
ECD_{50} (μm) (8 L/min)	34.1	22.2	14.5	9.5	6.2	4.1	2.7
Particle Size Range of Stage	>34.1	22.2 to 34.1	14.5 to 22.2	9.5 to 14.5	6.2 to 9.5	4.1 to 6.2	2.7 to 4.1

Figure 8 illustrates the particle size ranges collected by stage for both types of impactors. This demonstrates the wide range of particle diameters collected with two different impactor designs, with an overlap of several stages for comparison between the two impactors. Note that there is no upper bound on the size of particles collected on the first stage of both impactors. On each impactor, the seventh stage is followed by a back filter (0.8-μm pore size, not shown in figure 8), which collects most particles less than the ECD_{50} of the seventh stage.

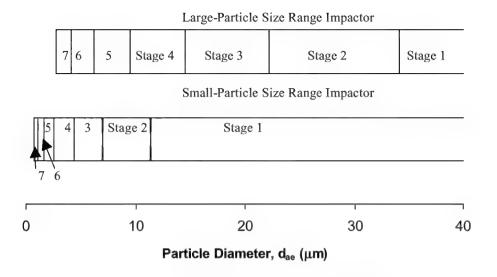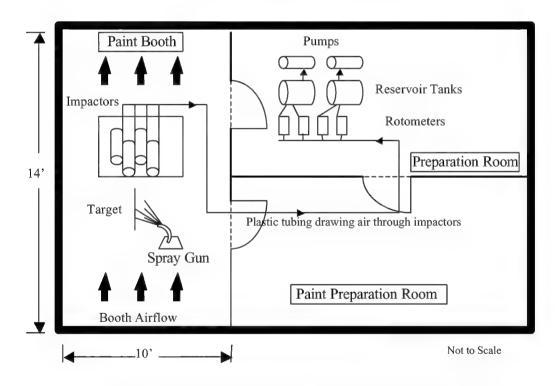**Figure 8. Particle Size Range by Stage**

Figure 9. Sampling System Layout at CTIO Paint Booth

Figure 9 illustrates the layout of the sampling system. Two Gast pumps provided the vacuum source for airflow through the impactors. Each pump supplied two impactors, on which individual valves equipped with rotameters regulated the airflow rates separately. A five-gallon receiving tank was attached in series to each pump (between the rotometer and the vacuum pump) as a means of balancing air flow fluctuations. Figure 10 shows the air flow control system for the impactors, which was located outside of the paint booth since the pumps are an ignition source and the paint poses a fire hazard. The hoses from the rotometer inlets continue under the booth door with the plastic tubing connecting to the impactors.

Figure 10. Sample Collection Vacuum Pumps with Rotometers

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Sample Preparation

After particles were collected, samples containing the captured paint particles were dried, weighed, and digested in preparation for analysis. Since each separate collection plate (seven stages plus one back plate per impactor) represents an individual sample, each painting run resulted in 16 individual samples (8 high range and 8 low range) that required preparation. This section documents the procedures followed for each sample.

Sample Substrates.

Overspray particles were collected on 0.22-μm (pore-size) cellulose ester filters (CEFs), manufactured by Millipore. These CEFs covered the entire surface area of the impaction plates, ensuring efficient capture of particles entering the impactors. The ease of removal of these filters from the impactors further improved the efficient transfer of collected particles into a sample solution for analysis. Additionally, CEFs are digestible, thus, eliminating the need for additional processing to remove collected sample from the filter before digesting.

Analytical Mass Determination.

Each CEF was weighed before and after the sampling event so that the dry mass of collected paint particulates could be determined for each stage. All weighing operations were conducted inside an air-tight glove box (which contained Drierite anhydrous calcium sulfate). To minimize fluctuation due to non-evaporated water and solvent content, each CEF was stored in the sealed glove box for 24 hours before taking the pre-paint mass and post-paint mass of the CEF. After weighing, the glove box was opened only for the brief time required to exchange a tray (one tray per painting run) of

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filters—less than ten seconds per tray. The glove box was never opened during the 24-hour drying periods leading up to the weighing or during the weighing operations.

All weighing operations were performed using a Mettler-Toledo microbalance model MT5 (precision 0.001 mg). Each sample was weighed and recorded in triplicate. Furthermore, each sample was passed through a Haug U-electrode ionizer model PRX-U prior to placing in the weighing chamber to reduce the effects of static charge carried by the filter.

Sample Digestion

Before a sample could be analyzed, the solid particles and filter must be digested into a liquid sample. Each paint sample (i.e., CEF and collected paint) was placed in a Teflon digestion vessel along with trace-metals grade, 70% (w/w) nitric acid and digested in an OI analytical microwave. 5.0 mL of the nitric acid were added to most samples, but due to the large mass of paint collected on some first-stage samples, as much as 20 mL of nitric acid was added for complete digestion. Sealed pressure vessels were loaded into carousels and digested according to a pressure-controlled program based on NIOSH method 7082—used for digestion of paint chips. Pressure was held at a minimum of 70 psig so that a minimum temperature of 140 degrees C was maintained for at least 20 min. Table 6 details the digestion program used.

Table 6. Sample Digestion Program

Stage	Power (%)	Set Point (psig)	Dwell Time (mm:ss)	Max Time (mm:ss)
1	75	20	02:00	03:00
2	100	70	20:00	30:00
3	0	0	02:00	02:00

Sample Dilution.

Following digestion, vessels were allowed to cool before opening. Once opened, the contents of the Teflon vessels were transferred into a 30-mL high-density polyethylene (HDPE) sample bottle. The Teflon vessels were triple rinsed with a total of 20 mL of deionized water. This rinsate was transferred to the HDPE bottle, yielding approximately 25-mL of sample for analysis.

More precise sample volumes were calculated based on the mass of each liquid sample. The mass of the liquid in each HDPE bottle was measured with a Mettler-Toledo balance model AB204-S (precision 0.1 mg). Based on the loaded filter weight and the densities of the 70% nitric acid and deionized water, the volume of sample contained in each HPDE bottle was calculated:

$$\text{Sample Volume } (mL) = \frac{m_{sample} - m_{filter+paint} - (V_{70\%} \cdot \rho_{70\%})}{\rho_{di}} + V_{70\%} \qquad (6)$$

where

m_{sample} = Net weight of liquid in HDPE sample bottle (g)
$m_{filter+paint}$ = Mass of CEF and paint sample (g)
$\rho_{70\%}$ = Density 70% nitric acid (g/mL)
ρ_{di} = Density of deionized water (g/mL)
$V_{70\%}$ = Volume of 70% nitric acid used for digestion (mL)

Based on these calculated sample volumes and the net mass of the paint collected on each filter, the mass of dry paint per unit volume of the liquid sample is known.

Sample Analysis

Analytical determination of the Cr^{6+} content in each sample was performed on a GBC Avanta atomic absorption spectrometer (AAS). This AAS is capable of sample

analysis using either a graphite furnace or flame method. The graphite furnace was used

for analysis of liquids expected to contain less than one part per million (ppm) chromium;

the flame method was used to analyze liquid samples expected to contain between 1 and

15 ppm. When necessary a sample was diluted, either manually or automatically (by the

AAS), so that the chromium concentration was within the calibration range of the

method.

For the graphite furnace method, a five-point (7.5, 20, 40, 60, 75-parts per billion

(ppb)) calibration ($R^2 > 0.98$) was performed using the auto-dilution feature on the AAS

with a certified 75-ppb Cr standard. Three replicate measurements per sample were

performed. A 75-ppb check sample was performed for at least every ten samples

analyzed for quality assurance. Each check sample was followed by a sample blank to

detect for instrument drift. The auto-dilution feature was able to dilute samples

containing more than 75 ppb Cr. For these samples above the calibration range, up to

two consecutive 1:4 dilutions were performed using deionized water. Table 7

summarizes the method for the graphite furnace.

Table 7. AAS Graphite Furnace Parameters

Step	Final Temp. (C)	Ramp Time (s)	Hold Time (s)	Gas
Step 1: Inject Sample				
Step 2: Drying	80°	5	10	Argon
Step 3: Charing	130°	30	10	Argon
Step 4: Pyrolysis	1400°	15	15	Argon
Step 5: Atomize/Read	2500°	1.4	1.6	None
Step 6: Tube Clean	2700°	0.5	1.5	Argon

For samples containing chromium concentrations greater than one ppm, an air-

acetylene flame method was used. A four-point (1, 5, 10, and 15-ppm) calibration ($R^2 >$

0.98) was performed using standards prepared from a certified 250-ppm standard. To ensure consistent atomization, a fuel/oxidant ratio of approximately 1.8/10 was maintained for all samples analyzed by this method. Quality assurance measures identical to those described for the graphite furnace method were implemented for flame atomization using a 10-ppm standard. Since auto-dilution was not available for the flame atomizer, all samples containing over 15 ppm Cr were manually diluted if the sample was above the calibration range for the instrument.

Calculation of Chromium Content in Dry Paint

Chromium concentrations reported by the AAS (μg Cr/L sample) were divided by the mass of dry paint collected in each sample to calculate the Cr^{6+} content

$(\dfrac{\mu g\ Cr^{+6}}{\mu g\ dry\ paint} x100\%)$ in different size ranges of particles collected. Equation 7 was used to calculate the chromium content in dry paint on the CEF for each stage:

$$\frac{\mu g\ Cr^{+6}}{\mu g\ dry\ paint} = \frac{C_{AAS} \cdot V_{sample}}{m_{paint}} \qquad (7)$$

where

C_{AAS} = AAS reported concentration [corrected for dilution, if necessary] (μg/L)
V_{sample} = sample volume [calculated from Equation (6)] (L)
M_{paint} = Mass of dry paint sample (μg)

Cr^{6+} Content per Mass of Dry Paint

Table 8 presents the results of the Cr^{6+} analysis as a function of particle size range collected (by impactor stage) for the three primer paints. The number of samples in each particle size range (n) and the standard deviation of the sample mean (SD) are listed for each primer type.

Table 8. Average Cr^{6+} Content per Mass of Dry Primer Paint

Stage*	Particle Size Range	Solvent-Based Epoxy-Polyamide			Water-Based Epoxy-Polyamide			Solvent-Based Elastomeric Polyurethane		
#	(μm)	Mean %Cr^{6+}	SD	n	Mean %Cr^{6+}	SD	n	Mean %Cr^{6+}	SD	n
S7	0.7 ≤d_{ae}< 1.0	0.99%	0.27%	7	0.67%	0.27%	14	0.36%	0.13%	10
S6	1.0 ≤d_{ae}< 1.6	1.18%	0.42%	8	0.72%	0.27%	15	0.51%	0.08%	10
S5	1.6 ≤d_{ae}< 2.6	1.74%	0.67%	8	1.15%	0.29%	16	0.90%	0.13%	10
S4	2.6 ≤d_{ae}< 4.3	2.48%	0.73%	8	2.89%	0.68%	16	1.65%	0.17%	10
L7	2.7 ≤d_{ae}< 4.1	2.90%	0.73%	6	1.89%	0.65%	16	1.70%	0.95%	9
L6	4.1 ≤d_{ae}< 6.2	4.77%	1.42%	7	4.95%	1.04%	14	2.51%	0.72%	9
S3	4.3 ≤d_{ae}< 7.0	4.41%	1.53%	5	4.97%	0.67%	14	2.79%	0.39%	10
L5	6.2 ≤d_{ae}< 9.5	6.17%	0.47%	5	6.50%	1.15%	15	3.77%	0.94%	10
S2	7.0 ≤d_{ae}< 11.4	7.09%	1.65%	8	6.56%	1.36%	16	3.72%	0.70%	10
L4	9.5 ≤d_{ae}< 14.5	7.20%	0.98%	6	6.67%	1.36%	14	3.86%	0.71%	9
L3	14.5 ≤d_{ae}< 22.2	5.17%	0.57%	6	6.27%	1.21%	13	3.76%	0.74%	9
L2	22.2 ≤d_{ae}< 34.1	4.45%	1.37%	6	5.57%	1.22%	14	3.60%	1.06%	10
L1	34.1 ≤d_{ae}	6.94%	1.99%	6	6.03%	1.29%	15	4.34%	0.51%	9

*S denotes small-particle size range impactor; L denotes large particle-size range impactor

The results of the analysis of the samples collected on the first stage of the small particle size range impactor (S1) were not reported. The mass of paint particles collected on the filters from S1 was so large that complete digestion could not be reliably accomplished.

Figures 11a-c display the mean percent Cr^{6+} plotted against the particle size range collected. Since some stages from the small and large particle size range impactors overlap, the stages for both impactor types are plotted in two different shades. Dark areas

represent stages of the small particle size range impactors; light areas are for the large particle size range impactor stages. The vertical range of percent Cr^{6+} plotted covers the 95% confidence interval about the mean. A solid line is included on each figure to show the expected Cr^{6+} content per mass of dry paint for the corresponding type of primer (as reported in Table 1). The particle size range collected by the largest stage displayed on these figures has no theoretical upper limit, although the figures are arbitrarily truncated at 40 μm. Nevertheless, it is unlikely that an appreciable number of larger particles entered the impactor as these particles would have impacted on the cardboard target.
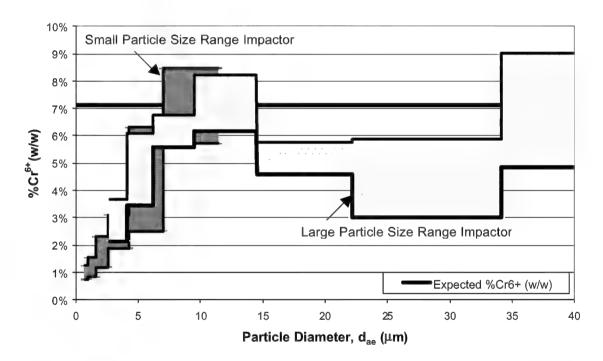
Figure 11a. Mass of Cr^{6+} per Mass of Dry Paint: Solvent-Based Epoxy-Polyamide
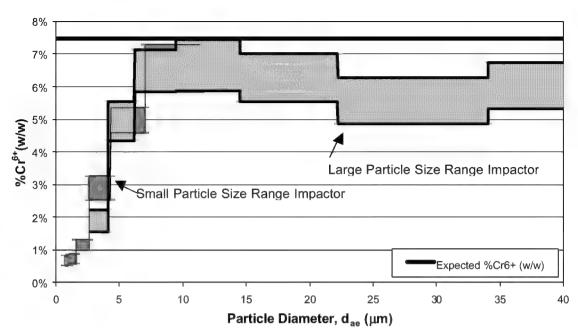
Figure 11b. Mass of Cr^{6+} per Mass of Dry Paint: Water-Based Epoxy-Polyamide
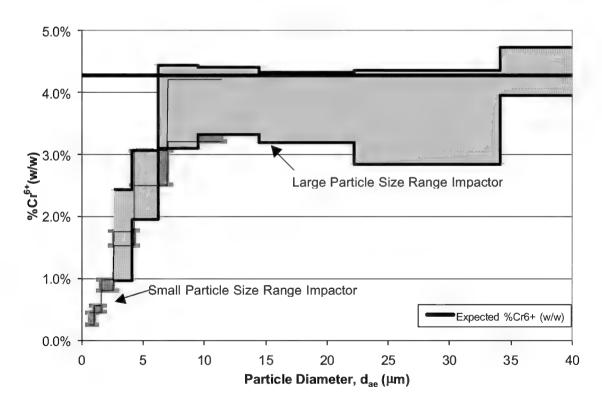

Figure 11c. Mass of Cr^{6+} per Mass of Dry Paint: Solvent-Based Elastomeric Polyurethane

A/P Ratio Influence on Cr^{6+} Content

Figures 12a-c show the mean percent Cr^{6+} plotted against the ECD_{50} for each impactor stage for the subsets of both the high and low A/P ratios. The percent Cr^{6+} is plotted as a function of the ECD_{50} value of each impactor stage to clearly compare the trends. The error bars on these figures enclose the 95% confidence interval about the mean percent Cr^{6+}. The data points for the high A/P ratio data series are slightly offset to the right so that the error bars for the two series of data are easier to distinguish.
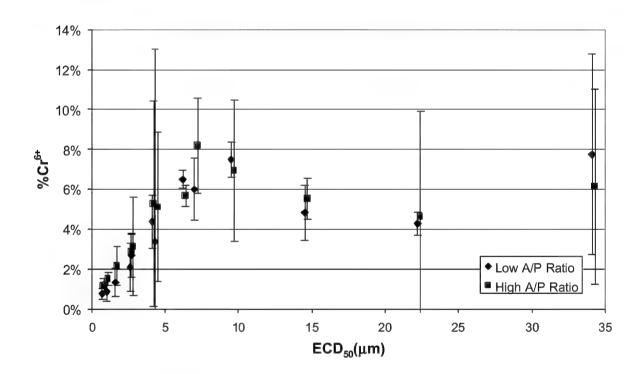

Figure 12a. Comparison of Mean Percent Cr^{6+} for Different A/P Ratios:
Solvent-Based Epoxy-Polyamide
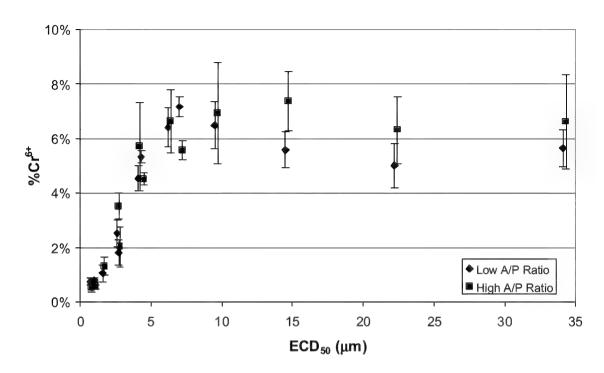**(Bars represent 95% confidence interval about mean)**

Figure 12b. Comparison of Mean Percent Cr^{6+} for Different A/P Ratios:
Water-Based Epoxy-Polyamide
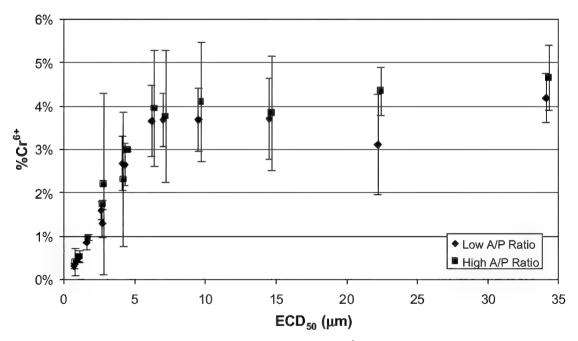**(Bars represent 95% confidence interval about mean)**

Figure 12c. Comparison of Mean Percent Cr^{6+} for Different A/P Ratios:
Solvent-Based Elastomeric Polyurethane
(Bars represent 95% confidence interval about mean)

The means of the high and low A/P ratio categories were compared for each stage using a paired Student's t analysis. For both epoxy-polyamide primers, the mean percent Cr^{6+} for at least two stages were found to be statistically different (at the $\alpha = 0.05$ level). However, due to the small sample sizes and the lack of any repeatable trend, these data suggest that practical variations in the A/P ratios do not impact the Cr^{6+} bias to any appreciable degree.

Comparison of Cr^{6+} Content Bias to Previous Study

Figure 13 compares the Cr^{6+} content bias found in the solvent-based epoxy-polyamide primer paint during this study to the Cr^{6+} content bias reported by Novy (2001) on the same military specification primer from the same manufacturer. The agreement of the data indicates a high degree of repeatability between these studies. The error bars shown in Figure 13 contain the 95% confidence interval about the mean.
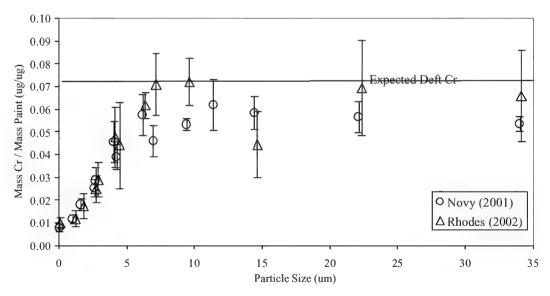

Figure 13. Comparison of Mass of Cr^{6+} per Mass of Dry Paint by Study

V. Discussion

Cr^{6+} Content Bias in Different Primers

The mean percent Cr^{6+} of the largest particle sizes collected closely match the expected Cr^{6+} content in the dry paint. For all three primers, the Cr^{6+} content per mass of dry paint in the last five stages ($d_{ae} < 7.0$ µm) of the small particle size range impactor and the last two stages ($d_{ae} < 6.2$ µm) of the large particle size range impactor was significantly less than the expected Cr^{6+} (at the $\alpha=0.05$ level of confidence). With the exception of the water EP primer, the mean Cr^{6+} content of the largest stage ($d_{ae} > 34.1$ µm) was within 2% of the expected value. This observation suggests that the Cr^{6+} content in the larger particles is similar to that of the solids fraction of the homogeneous, mixed primer paint.

The largest particles collected of the water-based epoxy-polyamide primer contained less than the expected amount of Cr^{6+} per mass of dry paint (at the $\alpha=0.05$ level of confidence). This may be due to water content in the collected paint particles that did not evaporate during the drying phase. Water-based primers have been noted for the slow removal of water during the curing process (Mitchell, 2002). The high reactivity of water with the epoxy resins may have caused some of the water to remain in the dry paint, which would add mass to the dry paint, thus lowering the measured percent Cr^{6+} in the dry paint. Nevertheless, the overall trend of the Cr^{6+} content in the water EP primer followed that of the other two primers. This bias is expected to be less prevalent with smaller particles since water may be able to escape more easily with the larger surface area to volume ratio.

Influence of A/P Ratio on Cr^{6+} Content

The variation of the A/P ratio during paint atomization did not have a discernable effect on the Cr^{6+} content of the particles. Testing over a greater range of A/P ratios may have produced different results. However, the range of A/P ratios tested in this study reflects the normal operating conditions in the field. Higher or lower A/P ratios would have produced unacceptable spray patterns or would not have been possible with an HVLP gun.

Implications of Cr^{6+} Content Bias

The repeatable, disproportionate decrease in Cr^{6+} in the smaller particles of the primer overspray has implications on the health hazards to aircraft spray painters. Considering the dependence of particle size on the penetration depth of an airborne particle in the respiratory system, the bias in Cr^{6+} content may lead to a lower estimate of Cr^{6+} exposure than previously thought. Since smaller particles tend to deposit deeper in the lungs, less Cr^{6+} per mass of material inhaled is delivered than expected if one assumes a uniform distribution of Cr^{6+} throughout the particle size distribution of the overspray. The results presented here indicate that particles capable of reaching the alveolar sacs in the pulmonary region of the lungs—generally $d_{ae}<2.5\mu m$—have only about one-third of the Cr^{6+} that is present in the larger particles.

Figures 14a-16b show an estimate of the Cr^{6+} deposition in the three main regions of the lung—nasopharyngeal, tracheobronchial, and pulmonary—based on the mass of Cr^{6+} collected for each type of primer. A pair of stacked bars are plotted for each region of the lung—one representing the experimentally determined mass of Cr^{6+} collected (the left bar of each pair) and one representing the mass of Cr^{6+} in the collected mass of dry

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paint based on the assumption that Cr^{6+} is uniformly distributed throughout all particle sizes in the primer overspray (the right bar of each pair). The relative contribution of particles from each impactor stage is shown in the bars. The stages are stacked with those representing largest particles on the bottom and smallest particles on the top. These figures are based assumed probabilities of the median size particle of a stage depositing in each region of the lung. The assumed probabilities were taken from Figure 1.

Figures 14a-16b demonstrate the impact that the disproportionate decrease of Cr^{6+} in smaller particles has on the overall mass of Cr^{6+} delivered to each region of the lung. The impact is more pronounced in Figures 14a, 15a, and 16a since these represent data from the small particle-size range impactors. In general, the areas corresponding to stages representing larger particle sizes do not change from the left bar to the right bar since the Cr^{6+} content closely matched the expected Cr^{6+} content in dry paint.
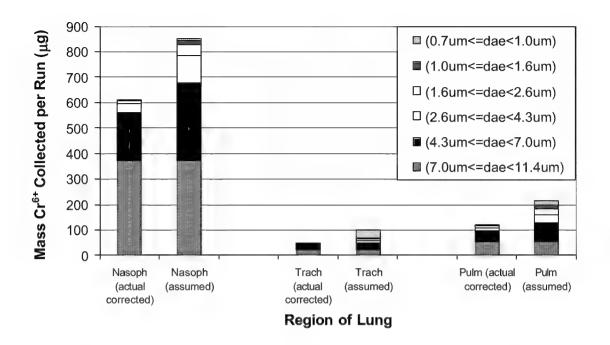
Figure 14a. Cr^{6+} Deposition in Lung: Solvent-Based Epoxy-Polyamide
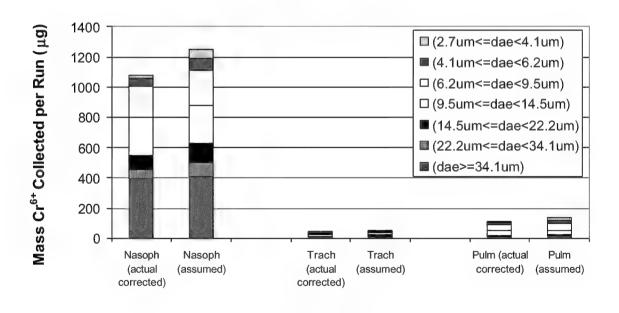(Small Particle-Size Impactor)

Figure 14b. Cr^{6+} Deposition in Lung: Solvent-Based Epoxy-Polyamide
(Large Particle-Size Impactor)

Note: -Nasoph=Nasopharyngeal, Trach=Tracheobronchial, Pulm=Pulmonary
-Order of areas in bars matches order listed in legend (top to bottom)

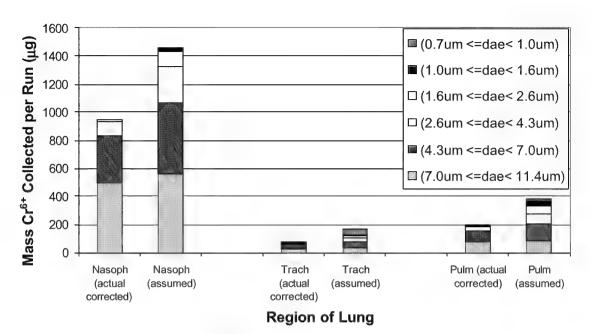**Figure 15a. Cr^{6+} Deposition in Lung: Water-Based Epoxy-Polyamide (Small Particle-Size Impactor)**
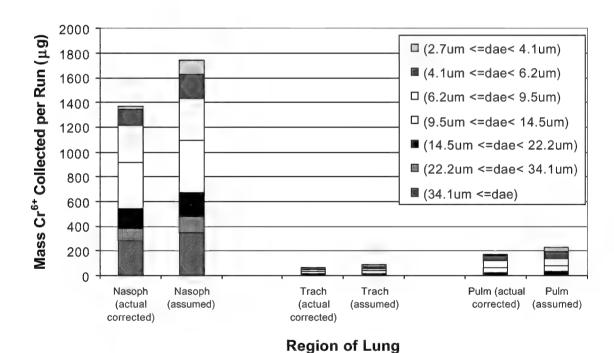

Figure 15b. Cr^{6+} Deposition in Lung: Water-Based Epoxy-Polyamide (Large Particle-Size Impactor)

Note: -Nasoph=Nasopharyngeal, Trach=Tracheobronchial, Pulm=Pulmonary
-Order of areas in bars matches order listed in legend (top to bottom)
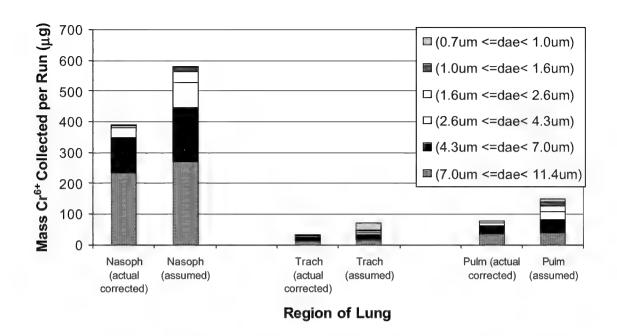
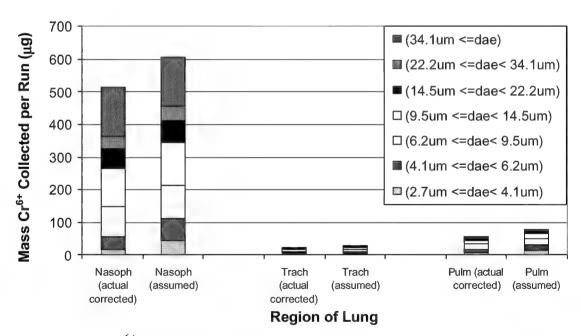**Figure 16a. Cr^{6+} Deposition in Lung: Solvent-Based Elastomeric-Polyurethane (Small Particle-Size Impactor)**

Figure 16b. Cr^{6+} Deposition in Lung: Solvent-Based Elastomeric-Polyurethane (Large Particle-Size Impactor)

Note: -Nasoph=Nasopharyngeal, Trach=Tracheobronchial, Pulm=Pulmonary
-Order of areas in bars matches order listed in legend (top to bottom)

As noted by LaPuma *et al.*, the Cr^{6+} bias may also merit the examination of practices used to estimate the fugitive emissions of Cr^{6+} from industrial paint booths (LaPuma *et al.*, 2001:348). Since filter efficiency increases with increasing particle size, the smaller, lower Cr^{6+}-containing particles in overspray are more likely to escape filtration than larger particles that contain more Cr^{6+}. With the similarity in the bias of the three primers studied, it is likely that the emission of Cr^{6+}, and possibly other inorganic solids, is overestimated.

Possible Sources of Cr^{6+} Bias

Although the exact mechanism explaining the Cr^{6+} bias is not known, it is likely that the atomization process itself is responsible for the heterogeneous distribution of Cr^{6+} in the overspray. One of the methods of secondary atomization described earlier may have caused the shearing of small, non-Cr^{6+}-containing droplets off of larger droplets that contained solid $SrCrO_4$ particles in the core of the droplet. Also, it is possible that some of the smaller particles were formed during initial atomization were too small to contain the larger, solid particles of $SrCrO_4$. The relatively smaller Cr^{6+} concentration detected in these small particles would most likely come from dissolved Cr^{6+} in the paint mixture, which is relatively small compared to the Cr^{6+} present in solid form (i.e., $SrCrO_4$ powder).

APPENDIX A-1: Calculation for Cr^{6+} Content in Solvent EP

This appendix documents the calculations used to determine the percent (by mass) of Cr^{6+} in the dry paint being tested.

First, relevant data from the Product Data Sheets and MSDS are given.

Paint Type: Solvent-Based Epoxy-Polyamide Primer

Parameters from Product Data Sheets and MSDS:

Base Component Density (lbs/gal)	Primer Component Density (lbs/gal)	Percent (by mass) Cr^{6+} in Base Component	Percent (by mass) Solids in Mixed Primer Paint
11.21	7.76	25% (w/w)	72.72% (w/w)

Mix Ratio: 3 parts base component to 1 part catalyst component

Additional Information:

Atomic Weight of Cr^{6+}:   52.0 g/g-mole
Molecular Weight of $SrCrO_4$: 203.6 g/g-mole

Next, the density of the mixed primer is calculated based on the volumetric mix ratios of the primer components and the densities of these components.

Density of Mixed Primer Paint:

$$\left(\frac{3\,\text{parts base}}{4\,\text{parts mix}}\right)x\frac{11.21\,\text{lb}}{\text{gal}} + \left(\frac{1\,\text{part catalyst}}{4\,\text{parts mix}}\right)x\frac{7.76\,\text{lb}}{\text{gal}} = 10.35\,\frac{\text{lb}}{\text{gal}}\,\text{paint}$$

Given the calculated primer density, the percent (by mass) of $SrCrO_4$ was determined. The numerator represents the mass of $SrCrO_4$ in one gallon of mixed primer (note: All $SrCrO_4$ is from the base component; the catalyst contains no chromium.). The denominator represents the mass of mixed primer (i.e., the density of the mixed primer).

Percent (by mass) $SrCrO_4$ in Mixed Primer Paint:

$$\frac{25\% \text{ SrCrO}_4 \ x\left(\dfrac{3 \text{ parts base}}{4 \text{ parts mix}}\right) x \dfrac{11.21 \text{ lb}}{\text{gal}}}{10.35 \ ^{\text{lb}}\!\!\diagup\!\!_{\text{gal}} \text{ paint}} = 20.3\% \ (\text{w/w}) \text{SrCrO}_4$$

Next, the percent (by mass) of $SrCrO_4$ in the mixed primer was converted to the percent (by mass) of Cr^{6+} in the mixed primer. This conversion was based on the ratio of the atomic weight of chromium over the molecular weight of $SrCrO_4$.

Percent (by mass) Cr^{6+} in Mixed Primer Paint:

$$20.3\% \text{ SrCrO}_4 \ x \frac{52.0 \ ^{\text{g}}\!\!\diagup\!\!_{\text{g - mol}} \ \text{Cr}^{6+}}{203.6 \ ^{\text{g}}\!\!\diagup\!\!_{\text{g - mol}} \ \text{SrCrO}_4} = \underline{5.19\% \ (\text{w/w}) \ \text{Cr}^{6+} \text{ in Mixed Primer}}$$

Lastly, the percent (by mass) of Cr^{6+} in the dry primer was determined based on the fraction of non-volatiles in the mixed paint. Multiplying the percent Cr^{6+} in the "wet" primer by this fraction yields the percent Cr^{6+} in the "dry" paint.

Percent (by mass) Cr^{6+} in Dry Primer Paint:

$$5.19\% \ (\text{w/w}) \ \text{Cr}^{6+} \text{ in Mixed Primer } x \frac{.7272 \text{ lb dry paint}}{1 \text{ lb mixed paint}} = \underline{\underline{7.13\% \ (\text{w/w}) \ \text{Cr}^{6+} \text{ in Dry Paint}}}$$

This procedure was repeated for the Water EP and Polyurethane primers in Appendices A-2 and A-3.

APPENDIX A-2: Calculations for Cr^{6+} Content in Water EP

Paint Type: Water-Based Epoxy-Polyamide Primer

Parameters from Product Data Sheets and MSDS:

Base Component Density (lbs/gal)	Primer Component Density (lbs/gal)	Percent (by mass) Cr^{6+} in Base Component	Percent (by mass) Solids in Mixed Primer Paint
10.80	9.34	30% (w/w)	34.08% (w/w)

Mix Ratio: 2 parts base component to 1 part catalyst component with a 4.1 parts water reduction

Additional Information:

Atomic Weight of Cr^{6+}: 52.0 g/g-mole
Molecular Weight of SrCrO$_4$: 203.6 g/g-mole
Water Density: 8.34 lbs/gal

Density of Mixed Primer Paint:

$$\left(\frac{2\,\text{parts base}}{7.1\,\text{parts mix}}\right)x\frac{10.80\,\text{lb}}{\text{gal}}+\left(\frac{1\,\text{part catalyst}}{7.1\,\text{parts mix}}\right)x\frac{9.34\,\text{lb}}{\text{gal}}+\left(\frac{4.1\,\text{parts water}}{7.1\,\text{parts mix}}\right)x\frac{8.34\,\text{lb}}{\text{gal}}=9.174\,\text{lb}\big/\text{gal}\,\text{paint}$$

Percent (by mass) SrCrO$_4$ in Mixed Primer Paint:

$$\frac{30\%\,\text{SrCrO}_4\,x\left(\dfrac{2\,\text{parts base}}{7.1\,\text{parts mix}}\right)x\dfrac{10.80\,\text{lb}}{\text{gal}}}{9.174\,\text{lb}\big/\text{gal}\,\text{paint}}=9.9\%\,(\text{w/w})\text{SrCrO}_4$$

Percent (by mass) Cr^{6+} in Mixed Primer Paint:

$$9.9\%\,\text{SrCrO}_4\,x\frac{52.0\,\text{g}\big/\text{g-mol}\;\text{Cr}^{6+}}{203.6\,\text{g}\big/\text{g-mol}\;\text{SrCrO}_4}=2.54\%\,(\text{w/w})\,\text{Cr}^{6+}\;\text{in Mixed Primer}$$

Percent (by mass) Cr^{6+} in Dry Primer Paint:

$$2.54\%\,(\text{w/w})\,\text{Cr}^{6+}\;\text{in Mixed Primer}\;x\frac{.3408\,\text{lb dry paint}}{1\,\text{lb mixed paint}}=7.46\%\,(\text{w/w})\,\text{Cr}^{6+}\;\text{in Dry Paint}$$

APPENDIX A-3: Calculations for Cr^{6+} Content in Polyurethane

Paint Type: Solvent-Based Elastomeric Polyurethane Primer

Parameters from Product Data Sheets and MSDS:

Base Component Density (lbs/gal)	Primer Component Density (lbs/gal)	Percent (by mass) Cr^{6+} in Base Component	Percent (by mass) Solids in Mixed Primer Paint
11.63	7.96	20% (w/w)	70.84% (w/w)

Mix Ratio: 1 part base component to 1 part catalyst component

Additional Information:

Atomic Weight of Cr^{6+}: 52.0 g/g-mole
Molecular Weight of $SrCrO_4$: 203.6 g/g-mole

Density of Mixed Primer Paint:

$$\left(\frac{1 \text{ parts base}}{2 \text{ parts mix}}\right) x \frac{11.63 \text{ lb}}{\text{gal}} + \left(\frac{1 \text{ part catalyst}}{2 \text{ parts mix}}\right) x \frac{7.96 \text{ lb}}{\text{gal}} = 9.795 \frac{\text{lb}}{\text{gal}} \text{ paint}$$

Percent (by mass) $SrCrO_4$ in Mixed Primer Paint:

$$\frac{20\% \, SrCrO_4 \, x \left(\frac{1 \text{ parts base}}{2 \text{ parts mix}}\right) x \frac{11.63 \text{ lb}}{\text{gal}}}{9.795 \frac{\text{lb}}{\text{gal}} \text{ paint}} = 11.87\% \, (w/w) SrCrO_4$$

Percent (by mass) Cr^{6+} in Mixed Primer Paint:

$$11.87\% \, SrCrO_4 \, x \frac{52.0 \frac{g}{g\text{-mol}} Cr^{6+}}{203.6 \frac{g}{g\text{-mol}} SrCrO_4} = 3.03\% \, (w/w) \, Cr^{6+} \text{ in Mixed Primer}$$

Percent (by mass) Cr^{6+} in Dry Primer Paint:

$$3.03\% \, (w/w) \, Cr^{6+} \text{ in Mixed Primer } x \frac{.7084 \text{ lb dry paint}}{1 \text{ lb mixed paint}} = 4.28\% \, (w/w) \, Cr^{6+} \text{ in Dry Paint}$$

DEFT.

PRODUCT INFORMATION DATA SHEET

Product Code Base Component--------------(02-Y-40)
Product Code Catalyst Component---------(02-Y-40 CATA.)
Batch Number of Base Component---------(L-12441)
Batch Number of Catalyst component----(L-12393)
Product to meet MIL specification ----------(MIL-P-23377G Type I Class C)
Product to meet Color -----------------------(Color : Strontium Chromate Yellow)
Mix or catalyst ratio------------------------------ (3:1 by volume)
Reduction ---(If Necessary)
Reducer ---(MIL-T-81772 Type II)

BASE CHARACTERISTICS

Wt./Gal.---------------------(11.21)
% solids by weight-------(73.10%)
% solids by volu'   -----(55.52%)
VOC pounds/gallon----(3.01)
VOC grams per liter---(362)

CATALYST CHARACTERISTICS

Wt./Gal.-----------------------(7.76)
% solids by weight----------(71.11%)
% solids by volume---------(67.64%)
VOC pounds/gallon---------(2.24)
VOC grams per liter---------(269)

CHARACTERISTICS AS APPLIED (NO REDUCTION)

Wt./Gal.---------------------(10.35)
% solids by weight-------(72.72%)
% solids by volume------(58.55%)
VOC pounds per gallon-(2.82)
VOC grams per liter-----(338)

Wt./Gal.of Solids------(12.85 lbs)
Sq./Ft. coverage @ 1
mil dry----------------------(937 Sq./Ft.)
          Grams per sq./Ft. @ 1
mil dry---------------------(3.68 grams)

QUALIFIED TEST RESULTS

(1) Pigment Composition (3.4.1.1)----Strontium Chromate --------------------56.40%
                          Siliceous Extender and
                          other additives = 48%--------------------43.60%
(2) Pigment Weight Percent of Base Component (3.4.1)= 37.0% min.-------- ---41.01%‰
(3) Fineness of Grind (ASTM Method D-1210) = 5 min.------------------------ 5
(4) Volatile Organic Compounds (VOC) content (3.4.2) = 340 grams
                                    per liter maximum ----------338 g./l.
(5) Storage Stability (3.5.3) 1 year at temperature of 35° to 115;f-----------------Pass
(6) Accelerated Storage Stability (3.5.4) 14 days at 140° +_ 5°F -----------------Pass
(7) Viscosity catalyzed and unreduced (3.6.3) = 40 seconds #4 ford Cup--------21 sec.
(8) Dry-Time (3.4.3)
              Set to Touch = No spec.--------------------------------1 hour
              Tack Free = 5 hours max.----------------------- -----5 hours
              Dry Hard = 8 hours max.---------------------------8 hours

(9) Condition in Container (3.5.1) ---(**Base Component**) Will stir into a smooth,
homogeneous condition.
(**Catalyst Component**) Will be clear & clean.

(10) Adhesion (3.7.4) No loss of adhesion after 24 hours of water immersion
at temperature of 65° to 85°F --------------------No Adhesion Loss

(11) Induction Time (4.5.1) 30 minutes maximum----------------------------30 min.

(12) Application of primer coating (4.5.1) Apply film at 0.6 to 0.9 mils----------0.9 mils

(13) Water Resistance (3.8.1) Topcoated primer immersed for 4 days
at 120°F +_5°F = No Defects----------------No defects
(sl. lose of color)

(14) Flexibility (3.7.5) Impact elongation = 10%----------------------------------

(15) Lifting 3.7.3) No lifting of MIL-C-85285B Polyurethane
Topcoat after:
Topcoat @ 2 hours (no spec.)------------------No Lifting
Topcoat @ 3 hours (no spec.)------------------No Lifting
Topcoat @ 5 hours----------------------------No Lifting

(16) Strippability 3.7.6) Within 60 minutes with a stripper conforming
to MIL-R-81294, Type 1 = 90% minimum----------------99%

(17) Salt Spray Resistance (3.8.2.1.1) 2000 hours with a 5% solution
No blistering, lifting or corrosion--------No Defect

(18) Topcoating (3.5.11) To be topcoated with a polyurethane conforming
to MIL-C-85285B, Color # 17925---------------------No lifting

(19) Filiform (3.8.2.2) After 1000 hours at 104°F and a relative
humidity of 80 +_5% = No Defects-----------------------No Defects

(20) Pot-Life (3.6.4) After 4 hours at room temperature 65° to 85°F
catalyzed and unreduced =70 seconds maximum------------30 sec.

(21) Fluid Resistance (3.8.4) No softening, blistering, loss of adhesion
or film defects after 24 hours at 250°F
MIL-L-23699--No Defects
MIL-H-83282--No Defects

EPOXY POLYAMIDE PRIMER DESCRIPTION AND APPLICATION INFORMATION

DESCRIPTION :

Chemically cured two component epoxy-polyamide primer suitable for
application on aircraft and aerospace equipment. Component I
contains the pigment and epoxy resin. Component II is the clear
non-pigmented aliphatic polyamine-epoxy portion which acts as the
hardener or curing agent for Component 1.

AIR POLLUTION REGULATIONS :

This product is formulated for use where the air pollution regulations
call out for a maximum VOC of 340 grams per liter.

SPECIAL FEATURES :

This epoxy-polyamide primer is a solvent borne, corrosion inhibiting
and chemical and solvent resistant primer

APPLICATION :

This primer will spray satisfactorily in all respects and shall show no
running, sagging or streaking. The dry film shall show no dusting,
mottling or color separation and shall present a smooth finish free
from seeds. The standard film thickness shall be 0.6 to 0.9 mils dry.

APPENDIX B-2: Deft® MSDS for
Solvent-Based Epoxy-Polyamide Primer Paint
(MIL-P-23377G, Type I, Class C)

SECTION I - PRODUCT INDENTIFICATION

Manufacturer: DEFT, INC. (CAGE CODE 33461)   Information Phone: (949) 474-0400
              17451 VON KARMAN AVENUE   Emergency   Phone: (800) 424-9300
                                               CHEMTREC   Phone: 800-424-9300

              IRVINE   CA
              92614

| | Hazard Ratings: | Health - 4 |
| | none -> extreme | Fire - 3 |
Product Class : TYPE I, CLASS C
Trade Name   : MIL-PRF-23377G (MIL-P-23377G)   0 ---> 4   Reactivity - 1
Product Code : 02Y040
C.A.S. Number: NONE

SECTION II - HAZARDOUS INGREDIENTS

| | | Weight | ACGIH | | OSHA | | V.P. |
Ingredients	CAS #	%	TLV	STEL	PEL	STEL	mm HG
BENZENE, 1-CHLORO-4 TRIFLUOROMETHYL	98-56-6	< 5.	N.E.	N.E.	N.E.	N.E.	3.3 @ 68F
BENZENE, 1-CHLORO-2 TRIFLUOROMETHYL	88-16-4	< 0.1	N.E.	N.E.	N.E.	N.E.	3.3 @ 68F
n-BUTYL ACETATE	123-86-9	< 5.	150 ppm	200 ppm	150 ppm	200 ppm	13 @ 68F
METHYL n-PROPYL KETONE	107-87-9	25.	200 ppm	250 ppm	200 ppm	250 ppm	27.8 @ 68F
STRONTIUM CHROMATE	7789-06-2	25.			.1 ppm	N.E.	

The ACGIH TWA for Strontium Chromate (CAS 7789-06-2) as Cr is 0.0005 mg/m3.

AROMATIC HYDROCARBON	64742-95-6	< 1.	N.E	N.E	N.E.	N.E.	3 @ 68F
XYLENE	1330-20-7	< 0.1	100 ppm	150 ppm	100 ppm	150 ppm	5.1 @ 68F
1,2,4 TRIMETHYLBENZENE	95-63-6	< 1	100 ppm	150 ppm	100 ppm	N.E.	
CUMENE	98-82-8	< 0.1	50 ppm	N.E.	50 ppm	N.E.	
1,3,5 TRIMETHYLBENZENE	108-67-8	< 1	N.E	N.E	N.E.	N.E.	
DIETHYLBENZENE	25340-17-4	< .	N.E.	N.E	N.E.	N.E.	
ETHYL BENZENE	100-41-6	< 0.1	125 ppm	125 ppm	100 ppm	125 ppm	7.1 @ 63F

IARC has determined that ethylbenzene is possibly carcinogenic to humans

N-METHYLPYRROLIDONE	872-50-4	< 1.	N.E.	N.E	N.E.	N.E.	.5 @ 77F

N METHYLPYRROLIDONE, CAS # 872-50-4, ESTIMATED TLV TWA 100 PPM. (PER MAP ORIENTATION)

THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST
ALSO ANY UNLISTED INGREDIENTS

N.E. = Not Established

SECTION III - PHYSICAL DATA

Boiling Range: 213 - 396 Deg. F   Vapor Density: Heavier than Air
Evap. Rate: 1.66   x   n-Butyl Acetate   Liquid Density: Heavier than Water
Volatiles vol % 44.8   Wgt% 27.6   Wgt per gallon   11.71 Pounds
                                          Spec Gravity   1.34814

Appearance: YELLOW LIQUID WITH SOLVENT ODOR
    V.O.C : 361 G/L
SOLUBILITY IN WATER: Insoluble   PH: Not applicable
AUTOIGNITION TEMPERATURE: No information found
DECOMPOSITION TEMPERATURE: No information found
CORROSION RATE: No information found
VISCOSITY Thin liquid to heavy viscous material

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flammability Class: IB   Flash Point: 46 F (CC) LEL: 0.90% UEL: 10.50%
-EXTINGUISHING MEDIA:
    FOAM ALCOHOL FOAM, CO2, DRY CHEMICAL, WATER FOG**
-SPECIAL FIREFIGHTING PROCEDURES:
    Full fire fighting equipment with self-contained breathing
    apparatus and full protective clothing should be worn by fire
    fighters. Water may be used to cool closed containers to prevent
    pressure build-up, auto ignition or explosion.
UNUSUAL FIRE & EXPLOSION HAZARDS:
    Keep containers tightly closed. Isolate from heat, sparks,
    electrical equipment and open flame. Closed containers may
    explode when exposed to extreme heat. Application to hot
    surfaces requires special precautions. During emergency
    conditions overexposure to decomposition products may cause a
    health hazard. Symptoms may not be immediately apparent.

SECTION V - HEALTH HAZARD DATA

PERMISSIBLE EXPOSURE LEVEL
    SEE SECTION II, HAZARDOUS INGREDIENTS
-EFFECTS OF OVEREXPOSURE
    INHALATION: Irritation of the respiratory tract & acute nervous
    system depression characterized by the following progressive
    steps: headache, dizziness, staggering gait, confusion,
    unconsciousness or coma.
    SKIN AND EYE CONTACT: SKIN: Contact with the skin can cause
    irritation. Symptoms may be swelling, redness, and rash

MATERIAL SAFETY DATA SHEET   Printed : 07/19/01
For Coatings, Resins and Related Materials

Revised : 07/09/01

SECTION I - PRODUCT IDENTIFICATION

Manufacturer: DEFT, INC. (CAGE CODE 33461)   Information Phone: (949) 474-0400
              17451 VON KARMAN AVENUE   Emergency   Phone: (800) 424-9300
                                              CHEMTREC   Phone: 800-424-9300
              IRVINE   CA
              92614

Product Class: TYPE I, CLASS C | Hazard Ratings: Health - 3
Trade Name : MIL-PRF-23377G (MIL-P-23377G)| none -> extreme   Fire - 3
Product Code : 02T040CAT | 0 ---> 4   Reactivity - 1
C.A.S. Number: NONE |

SECTION II - HAZARDOUS INGREDIENTS

Ingredients	CAS #	Weight %	ACGIH TLV	ACGIH STEL	PEL	OSHA STEL	VP mm HG
ALIPHATIC AMINE	80-05-7	5.	N.E.	N.E.	N.E.	N.E.	
	Contains Bisphenol A (CAS # 80-05-7) less than 55%						
ALIPHATIC AMINE	25154-52-3	< 5.	N.E.	N.E.	N.E.	N.E.	
	Contains Bisphenol A (CAS # 80-05-7) less than 55%						
ALIPHATIC AMINE	103-83-3	< 1.	N.E.	N.E.	N.E.	N.E.	
	Contains Bisphenol A (CAS # 80-05-7) less than 55%						
ALIPHATIC AMINE	140-31-8	5.	N.E.	N.E.	N.E.	N.E.	
	Contains Bisphenol A (CAS # 80-05-7) less than 55%						
sec-BUTYL ALCOHOL	78-92-2	30.	100 ppm	N.E.	100 ppm	N.E.	12.5 @ 68F
AROMATIC HYDROCARBON	64742-95-6	< 1.	N.E.	N.E.	N.E.	N.E.	3 @ 68F
XYLENE	1330-20-7	< 0.1	100 ppm	150 ppm	100 ppm	150 ppm	5.1 @ 68F
1,2,4 TRIMETHYLBENZENE	95-63-6	< 1.	100 ppm	150 ppm	100 ppm	N.E.	
CUMENE	98-82-8	< 0.1	50 ppm	N.E.	50 ppm	N.E.	
1,3,5 TRIMETHYLBENZENE	108-67-8	< 1.	N.E.	N.E.	N.E.	N.E.	
DIETHYLBENZENE	25340-17-4	< 0.1	N.E.	N.E.	N.E.	N.E.	
ETHYL BENZENE	100-41-4	< 0.1	100 ppm	125 ppm	100 ppm	125 ppm	7.1 @ 68F
	IARC has determined that ethylbenzene is possibly carcinogenic to humans.						
AMINO SILANE ESTER	1760-24-3	< 1.	200 ppm	250 ppm	200 ppm	250ppm	
EPOXY RESIN HARDENER	90-72-2	< 5.	N.E.	N.E.	N.E.	N.E.	0 @ 70F
EPOXY RESIN HARDENER	71074-89-0	< 1.	N.E.	N.E.	N.E.	N.E.	0 @ 70F

THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST.
ALSO ANY UNLISTED INGREDIENTS.

N.E. = Not Established

SECTION III - PHYSICAL DATA

Boiling Range: 211 - 401 Deg. F   Vapor Density: Heavier than Air.
Evap. Rate: 0.63 x n-Butyl Acetate Liquid Density: Lighter than Water.
Volatiles vol % 34.8   Wgt% 29.7   Wgt per gallon: 7.90 Pounds.
                                        Spec. Gravity: 0.94838

Appearance: AMBER LIQUID WITH SOLVENT ODOR
   V.O.C.: 281
SOLUBILITY IN WATER: Insoluble   PH: Not applicable
AUTOIGNITION TEMPERATURE: No information found
DECOMPOSITION TEMPERATURE: No information found
CORROSION RATE: No information found
VISCOSITY: Thin liquid to heavy viscous material

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flammability Class: IB   Flash Point:67 F TCC LEL: 0.90% UEL: 9.80%
-EXTINGUISHING MEDIA:
   FOAM, ALCOHOL FOAM, CO2, DRY CHEMICAL, WATER FOG
-SPECIAL FIREFIGHTING PROCEDURES:
   Full fire fighting equipment with self-contained breathing
   apparatus and full protective clothing should be worn by fire
   fighters. Water may be used to cool closed containers to prevent
   pressure build-up, auto ignition or explosion.
-UNUSUAL FIRE & EXPLOSION HAZARDS:
   Keep containers tightly closed. Isolate from heat, sparks,
   electrical equipment and open flame. Closed containers may
   explode when exposed to extreme heat. Application to hot
   surfaces requires special precautions. During emergency
   conditions overexposure to decomposition products may cause a
   health hazard. Symptoms may not be immediately apparent.

SECTION V - HEALTH HAZARD DATA

-PERMISSIBLE EXPOSURE LEVEL:
   SEE SECTION II, HAZARDOUS INGREDIENTS.
-EFFECTS ON OVEREXPOSURE:
   INHALATION: Irritation of the respiratory tract & acute nervous
   system depression characterized by the following progressive
   steps: headache, dizziness, staggering gait, confusion,
   unconsciousness or coma.

APPENDIX C-1: Deft® Product Data Sheets for
Water-Based Epoxy-Polyamide Prime r Paint
(MIL-PRF-85582C, Type I, Class C)

PRODUCT INFORMATION DATA SHEET

Product Code Base Component	(44-GN-72 PROPOSED COLOR)
Product Code Catalyst Component	(44-GN-72 Cata.)
Batch Number of Base Component	(L-13265)
Batch Number of Catalyst component	(L-13266)
Product to meet Specification	(MIL-PRF-85582C Type I, Class C2)
Product to meet Color	(Color : PROPOSED COLOR)
Mix or catalyst ratio	(2:1 by volume)
Reduction	(4 Parts by volume , approximate)
Reducer	(Distilled or Deionized Water)

BASE CHARACTERISTICS

Wt./Gal.----------------(10.80)
% solids by weight------(74.25%)
% solids by volume------(58.77%)
VOC pounds/gallon----(2.80)
VOC grams per liter----(333)

CATALYST CHARACTERISTICS

Wt./Gal.----------------(9.34)
% solids by weight----------(69.28%)
% solids by volume----------(67.16%)
VOC pounds/gallon----------(2.87)
VOC grams per liter----------(344)

CHARACTERISTICS AS CATALYZED (NO REDUCTION)

Wt./Gal.----------------(10.37)
% solids by weight--------(71.75%)
% solids by volume--------(61.57%)
VOC pounds per gallon---(2.81)
VOC grams per liter-------(337)

Wt./Gal.of Solids----------(12.08 lbs)
Sq./Ft. coverage @ 1
mil dry---------------------(987 Sq./Ft.)
Grams per sq./Ft. @ 1
mil dry---------------------(3.46 grams)

QUALIFIED TEST RESULTS

1. Classification : (Para.1.2) Type I = Standard Pigment .... Passes
   Class C2 = Strontium Chromate .... Passes
2. Physical Properties : (3.4.1) Color
   Type I The color of the admixed type I primer coating shall be the natural color of the
   Corrosion inhibiting pigments used or darker........................ Passes
3. Fineness Of Grind : (Para.3.4.3) The fineness of grind of the admixed primer coating
   At application viscosity shall be not less than 5 5
4. Condition In Container : (Para.3.4.5) Component A and Component B will stir into a
   Smooth, homogeneous condition .... Passes
5. Pot-Life ; (Para.3.4.4) Viscosity at the start (# 4 Ford Cup) .... 20 sec.
   After 4 hours at room temperature of 73°F ± 5°F (when stirred
   constantly at 140 ± 30 rpm) = 8 seconds maximum increase .... 8 sec. max.
6. Storage Stability : (Para.3.4.6) This primer will meet all requirements after one year from
   the date of manufacturing when in an unopened container at a temperature of
   (35°F to 115°F) .... Passes
7. Accelerated Storage Stability : (Para.3.4.7) = 7 days at 120°F ± 1°F .... Passes

(Issued: 3 / 99)

9. Freeze Thaw Stability : (Para.3.4.8) This primer shall pass 5 cycles at 16 hours at
    15°F ± 5°F followed by 8 hours at 77°F per cycle ....Passes
10. Dry Time : (Para.3.5.2) Under an air flow of 88 feet per minute the primer shall dry
    as follows:
    (a) Tack Free (60 minutes maximum) ....60 minutes
    (b) Dry Hard (6 hours maximum) ....6 hours

13. Lifting : (Para.3.5.3) There shall be no lifting of the MIL-C-85285B Polyurethane Topcoat
    after the following:
    (a) Topcoat @ 2 hours...No Lifting
    (b) Topcoat @ 4 hours..No Lifting
    (c) Topcoat @ 18 hours..No Lifting
14. Adhesion – Wet Tape : (Para.3.5.4) No loss of adhesion after 24 hours of immersion
    in distilled water at room temperature (77°F) ....Passes
15. Flexibility : (3.5.5) The primer shall pass an Impact elongation of 10%......................Passes
16. Strippability : (Para.3.5.6) 90% of the primer will be stripped with in 15 minutes
    with remover conforming to MIL-R-81294 Class I at room temperature (77°F) ....Passes
17. Infrared Reflection (Para.3.5.7) Type II Primer Only : ....Passes
18. Water Resistance : (Para.3.6.1) The primer coating with and without a topcoat shall
    with-stand immersion in distilled water maintained at 49°±3°C for four days without
    exhibiting any evidence of softening, wrinkling, blistering or other deficiency ....Passes
19. Salt Spray : (Para.3.6.2.1) With and with-out Topcoat of polyurethane conforming
    to MIL-C-85285B shall show no blistering after 2000 hours at 5%
    (a) Aluminum ....Passes 2000 hours
    (b) Aluminum / Graphite Epoxy ....Passes 500 hours
20. Filiform : (3.6.2.2) Exhibit no filiform corrosion beyond ¼ inch from scribe.
    Majority of filaments less than 1/8 inch...Passes
21. Fluid Resistance : (Para.3.6.3) This primer shall withstand 24 hours immersion of
    the following:
    (a) MIL-L-23699 Lubricating Oil @ 250°F ± 5°F ....Passes
    (b) MIL-H-83282 Hydraulic Fluid @ 150°F ± 5°F ....passes

EPOXY POLYAMIDE, WATER REDUCIBLE PRIMER DESCRIPTION AND APPLICATION INFORMATION

DESSCRIPTION : Chemical cured two component epoxy polyamide water reducible primer for application on ferrous and non-ferrous metals. Component A contains the pigment and polyamide resin. Component B is the clear non-pigmented epoxy portion which acts as the hardener or curing agent for Component A.

AIR POLLUTION REGULATIONS : This product is formulated for use where the air pollution regulations call out for a maximum volatile organic compound (VOC) of 340 grams per liter.

SPECIAL FEATURES : This epoxy polyamide primer is a water reducible, corrosion inhibiting chemical and solvent resistant primer.

APPLICATION : This primer will spray satisfactorily in all respects and shall show no running, sagging or streaking. The dry film shall show no dusting, mottling or color separation and shall present a smooth finish free from seeds. The standard film thickness shall be 0.6 to 0.9 mils dry.

MIXING INSTRUCTIONS :

Component A	Component B	Water
2-Volumes	1-Volume	4.1-Volumes

Add all of the Catalyst Component to the short filled can containing the Base Component. Then use one of the following methods for mixing.

APPENDIX C-2: Deft® MSDS for
Water-Based Epoxy-Polyamide Primer Paint
(MIL-PRF-85582C, Type I, Class C)

                  SECTION   I - PRODUCT IDENTIFICATION

Manufacturer: ████████████████ ██ 33461)   Information Phone: (949) 474-0400
              17451 VON KARMAN AVENUE   Emergency   Phone: (800) 424-9300
                                              CHEMTREC   Phone: 800-424-9300
              IRVINE   CA
              92614

                                    ! Hazard Ratings: Health - 3
Product Class: TYPE I,CL C2,POLYAMIDE ! none -> extreme   Fire - 3
Trade Name : MIL-PRF-85582C, TY I, CL C2 ! 0 ---> 4   Reactivity - 1
Product Code : 44GN072   !
C.A.S. Number: NONE   !

                  SECTION II - HAZARDOUS INGREDIENTS

                                         -------------- Exposure Limits --------------
                                     Weight   ACGIH   OSHA   VP
Ingredients   CAS #   %   TLV   STEL   PEL   STEL   ██ MM

sec-BUTYL ALCOHOL   78-92-2   25.   100 ppm   N.E.   100 ppm   N.E. 12.5 @ 68F
C8&10 AROMATIC HYDROCARBON 64742-95-6 < 1.   N.E.   N.E.   N.E.   N.E.   3 @ 68F
                               Manufacturer recommends a PEL of 100 ppm.

STRONTIUM CHROMATE   7789-06-2   30.   .1 ppm   N.E.
                               The ACGIH TWA for Strontium Chromate (CAS 7789-06-2) as Cr
                               is 0.0005 mg/m3.

         THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST.
         ALSO ANY UNLISTED INGREDIENTS.

N.E. = Not Established

                  SECTION III - PHYSICAL DATA

Boiling Range: 211 - 335 Deg. F   Vapor Density: Heavier than Air.
Evap. Rate: 0.65 x   n-Butyl Acetate Liquid Density: Heavier than Water.
Volatiles vol % 43.1   Wgt% 26.9   Wgt per gallon: 10.80 Pounds.
                                      Spec. Gravity: 1.29652
Appearance: GREEN LIQUID WITH SOLVENT ODOR
      V.O.C.: 334
SOLUBILITY IN WATER: Insoluble   PH: Not applicable
AUTOIGNITION TEMPERATURE: No information found
DECOMPOSITION TEMPERATURE: No information found
CORROSION RATE: No information found
VISCOSITY: Thin liquid to heavy viscous material

                  SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flammability Class: IB   Flash Point:72 F TCC LEL: 1.00% UEL: 9.80%
-EXTINGUISHING MEDIA:
     FOAM, ALCOHOL FOAM, CO2, DRY CHEMICAL, WATER FOG
-SPECIAL FIREFIGHTING PROCEDURES:
     Full fire fighting equipment with self-contained breathing
     apparatus and full protective clothing should be worn by fire
     fighters. Water may be used to cool closed containers to prevent
     pressure build-up, auto ignition or explosion.
-UNUSUAL FIRE & EXPLOSION HAZARDS:
     Keep containers tightly closed. Isolate from heat, sparks,
     electrical equipment and open flame. Closed containers may
     explode when exposed to extreme heat. Application to hot
     surfaces requires special precautions. During emergency
     conditions overexposure to decomposition products may cause a
     health hazard. Symptoms may not be immediately apparent.

                  SECTION   V - HEALTH HAZARD DATA

-PERMISSIBLE EXPOSURE LEVEL:
     SEE SECTION II, HAZARDOUS INGREDIENTS.
-EFFECTS OF OVEREXPOSURE:
     INHALATION: Irritation of the respiratory tract & acute nervous
     system depression characterized by the following progressive
     steps: headache, dizziness, staggering gait, confusion,
     unconsciousness or coma.

     SKIN AND EYE CONTACT: SKIN: Contact with the skin can cause
     irritation. Symptoms may be swelling, redness, and rash.
     EYES: Liquid, aerosols, or vapors are irritating and may cause
     tearing, redness, and swelling accompanied by a stinging
     sensation.

     SKIN ABSORPTION: Prolonged or repeated contact can cause
     moderate irritation, drying, and defatting of the skin which can
     cause the skin to crack.

     INGESTION: Acute: Can result in irritation and possible
     corrosive action in the mouth, stomach tissue and digestive
     tract. Vomiting may cause aspiration of the solvent, resulting
     in chemical pneumonitis.

MATERIAL SAFETY DATA SHEET   Printed : 07/26/00
For Coatings, Resins and Related Materials
                                  Revised : 06/16/98

SECTION   I - PRODUCT IDENTIFICATION

Manufacturer: DEPT, INC. (CAGE CODE 33461)   Information Phone: (949) 474-0400
              17451 VON KARMAN AVENUE   Emergency   Phone: (800) 424-9300
                                               CHEMTREC   Phone: 800-424-9300

              IRVINE   CA
              92614

                                             | Hazard Ratings: Health - 3
Product Class: TYPE I,CL 2,EPOXY | none -> extreme   Fire - 3
Trade Name : COMP.B MIL-P-85582 TYPE 1, CLA!| 0   ---> 4   Reactivity - 1
Product Code : 44GN072CRT |
C.A.S. Number: NONE |

SECTION II - HAZARDOUS INGREDIENTS

			--------------- Exposure Limits ---------------				
			ACGIH		OSHA		VP
Ingredients	CAS #	Weight %	TLV	STEL	PEL	STEL	mm HG
NITROETHANE	79-24-3	30.	100 ppm	N.E.	100 ppm	N.E.	16 @ 68F

    THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST.
    ALSO ANY UNLISTED INGREDIENTS.

N.E. = Not Established

SECTION III - PHYSICAL DATA

Boiling Range: 237 - 300 Deg. F   Vapor Density: Heavier than Air.
Evap. Rate: 1.27 x   n-Butyl Acetate Liquid Density: Heavier than Water.
Volatiles vol % 32.2   Wgt% 30.1   Wgt per gallon: 9.38 Pounds.
                                        Spec. Gravity: 1.12605
Appearance: AMBER LIQUID WITH SOLVENT ODOR
   V.O.C.: 345 G/L
SOLUBILITY IN WATER: Insoluble   PH: Not applicable
AUTOIGNITION TEMPERATURE: No information found
DECOMPOSITION TEMPERATURE: No information found
CORROSION RATE: No information found
VISCOSITY: Thin liquid to heavy viscous material

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flammability Class: IC   Flash Point:87 F TCC LEL: 3.40% UEL: 0.00%
-EXTINGUISHING MEDIA:
    FOAM, ALCOHOL FOAM, CO2, DRY CHEMICAL, WATER FOG
-SPECIAL FIREFIGHTING PROCEDURES:
    Full fire fighting equipment with self-contained breathing
    apparatus and full protective clothing should be worn by fire
    fighters. Water may be used to cool closed containers to prevent
    pressure build-up, auto ignition or explosion.
-UNUSUAL FIRE & EXPLOSION HAZARDS:
    Keep containers tightly closed. Isolate from heat, sparks,
    electrical equipment and open flame. Closed containers may
    explode when exposed to extreme heat. Application to hot
    surfaces requires special precautions. During emergency
    conditions overexposure to decomposition products may cause a
    health hazard. Symptoms may not be immediately apparent.

SECTION   V - HEALTH HAZARD DATA

-PERMISSIBLE EXPOSURE LEVEL:
    SEE SECTION II, HAZARDOUS INGREDIENTS.
-EFFECTS OF OVEREXPOSURE:
    INHALATION: Irritation of the respiratory tract & acute nervous
    system depression characterized by the following progressive
    steps: headache, dizziness, staggering gait, confusion,
    unconsciousness or coma.

    SKIN AND EYE CONTACT: SKIN: Contact with the skin can cause
    irritation. Symptoms may be swelling, redness, and rash.
    EYES: Liquid, aerosols, or vapors are irritating and may cause
    tearing, redness, and swelling accompanied by a stinging
    sensation.

    SKIN ABSORPTION: Prolonged or repeated contact can cause
    moderate irritation, drying, and defatting of the skin which can
    cause the skin to crack.

    INGESTION: Acute: Can result in irritation and possible
    corrosive action in the mouth, stomach tissue and digestive
    tract. Vomiting may cause aspiration of the solvent, resulting
    in chemical pneumonitis.

    HEALTH HAZARDS (ACUTE AND CHRONIC)
    ACUTE: Vapors are irritating to eyes, nose, and throat.
    Inhalation may cause headaches, difficult breathing and loss of
    consciousness.

PRODUCT INFORMATION DATA SHEET

Product Code Base Component .... (09-Y-2)
Product Code Catalyst Component .... (09-Y-2 Cata.)
Batch Number of Base Component .... (L-12370)
Batch Number of Catalyst Component .... (L-10711)
Product to meet MIL Specification .... (TT-P-2760A Type I Class C)
Product to meet Color Number .... (Tinted To Improve Hiding As Per Specification)
Mix or Catalyst Ratio .... (1:1 By Volume)
Reduction .... (As VOC Will Allow)
Reducer .... (MIL-T-81772B Type I Polyurethane Reducer)

BASE CHARACTERISTICS

Wt./Gal. .... (11.63)
% solids by weight .... (81.65%)
% solids by volume .... (72.25%)
VOC pounds/gallon ...... (2.13)
VOC grams per liter ...... (255)

CATALYST CHARACTERISTICS

Wt./Gal. .... (7.96)
% solids by weight .... (55.06%)
% solids by volume .... (47.02%)
VOC pounds/gallon .... (3.54)
VOC grams per liter .... (424)

CHARACTERISTICS AS APPLIED (NO REDUCTION)

Wt./Gal. .... (9.79)
% solids by weight .... (70.84%)
% solids by volume .... (59.63%)
VOC pounds per gallon .... (2.83)
VOC grams per liter .... (340)

Wt./Gal. of solids .... (11.63)
Sq./ft. coverage @ 1 mil dry .... (954 Sq. / Ft.)
Grams per sq./ft. @ 1 mil dry .... (3.29 grams)

QUALIFIED TEST RESULTS

1. Scope: (Para.1.1) This is a low Volatile Organic Compound (VOC), solvent borne, elastomeric, polyurethane primer coating. This primer coating is formulated primarily for spray application. It is compatible with polyurethane topcoats and is intended for use on aircraft and other equipment subject to structural flexing at low temperatures.
2. Classification: (Para.1.2) The coating shall meet the following :
   Type I : Standard Pigments
   Class I : Strontium Chromate based corrosion inhibitors
3. Volatile Organic Compound (VOC) Content: The maximum VOC content of this primer coating at application shall be 340 grams per liter (2.80 lbs. per gallon). The resistivity of the solvents shall be suitable for electrostatic application.
4. Condition In Container: (3.5.1) The coating components shall be capable of being easily mixed by hand, with a paddle, to a smooth, homogeneous, pourable condition and free from gelation.
5. Storage Stability : (Para.3.5.2) The previously unopened packaged material shall be capable of meeting all requirements specified for a period of one year, when stored in an area where the daily temperature of the ambient air is with-in the range of (1.7°C to 46°C (35°F to 115°F).

6. Color : (Para.3.5.4) The color of the Type I primer coating shall be the natural color of the corrosion inhibiting pigment used with the exception that tinting to a darker shade is permitted to improve hiding power.

7. Fineness Of Grind : (Para.3.5.8) The fineness of grind, on the Hegman Scale shall be a minimum of 5 5

8. Viscosity : (Para.3.6.4) The viscosity of the admixed coating after thinning. Shall be in the range of 14 to 24 seconds through a (No. 4 Ford Cup) .... 21.78 sec.

9. Pot Life : (Para.3.6.5) After 2 hours in a closed container, the viscosity of the admixed coating shall not exceed 60 seconds through a No. 4 Ford Cup. The coating shall not gel with-in 4 hours after mixing.
Start 21.78 seconds #4 Ford Cup
After 4 hours 22.02 seconds, after 8 hours no gel.

10. Drying Time : (Para.3.7.1.) The coating shall be spray applied to a dry film thickness of (1 ¼ to 2 mils) Caution shall be taken when reducing the coating not to exceed the maximum allowable VOC content. The applied coating shall be allowed to dry at (70°F ± 10°F)
Tack Free (4-hours).. 4-hours
Dry Hard (8 hours)... 8-hours

11. Lifting : (Para.3.7.3) When separately applied to this primer coating that has air dried for 1,4 and 18 hours, the polyurethane topcoat shall exhibit no lifting or other film irregularity.

12. Adhesion : (Para.3.7.4) The primer shall not peel away from the substrate after immersion in water for 24 hours. .... Passes

13. Ambient Flexibility : (Para.3.7.5.1) The primer coating shall exhibit a minimum impact elongation of 60%... Passes

14. Low Temperature Flexibility : (Para.3.7.5.2) The primer coating shall exhibit no cracking when bent over a 1/8 inch mandrel at a temperature of -60°F .... Passes

15. Water Resistance : (Para.3.8.1) The primer with the polyurethane topcoat shall with-stand immersion for 4 days in distilled water at 120°F with-out exhibiting any softening, wrinkling, blistering, loss of adhesion or other deficiency.. Passes

16. Fluid Resistance : (Para.3.8.3) The primer shall exhibit no softening, blistering, loss of adhesion or other defects after immersion for 24 hours in the following:
MIL-L-23699 Lubricating Oil (@ 250°F).. Passes
MIL-H-83282 Hydraulic Fluid (@ 150°F).. Passes

17. Salt Spray : (Para.3.8.5.1) The primer coating shall exhibit no blistering, lifting of the coating or substrate corrosion after exposure to 5% salt spray for 2000 hours .... Passes

POLYURETHANE DESCRIPTION AND APPLICATION INFORMATION

DESCRIPTION: Chemically cured two component polyurethane elastomeric primer suitable for application on aircraft and aerospace equipment. Component A contains the pigment and the oil-free polyester resin. Component B is the clear non-pigmented aliphatic isocyanate prepolymer portion which acts as the hardener or curing agent for Component A.

PIGMENTS: Shall have exterior durability and be lead free.

AIR POLLUTION REGULATIONS: This product is suitable for use where the air pollution regulations call out for a maximum VOC of 340 grams per liter or les

SURFACE PREPARATION: This product is designed for use over deoxidized aluminum, chromic acid anodized aluminum, sulfuric acid anodized aluminum, titanium, magnesium, steel, fiberglass, and Alodine 1000, 1200 and 1500 equivalent pre treatments.

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APPENDIX D-2: Deft® MSDS
Solvent-Based Elastomeric Polyurethane Primer Paint
(TT-P-2760A, Type I, Class C)

                SECTION   I - PRODUCT IDENTIFICATION

Manufacturer: DEFT, INC. (CAGE CODE 33461)   Information Phone: (949) 474-0400
              17451 VON KARMAN AVENUE   Emergency Phone: (800) 424-9300
                                               CHEMTREC   Phone: 800-424-9300

              IRVINE   CA
              92614

                                        ! Hazard Ratings: Health - 4
Product Class: POLYURETHANE   ! none -> extreme   Fire - 3
Trade Name : TT-P-2760A TYP 1 CLASS C ! 0 ---> 4   Reactivity - 1
Product Code : 09Y002   !
C.A.S. Number: NONE   !   Personal Protection - I

                SECTION   II - HAZARDOUS INGREDIENTS

| | | Weight | ACGIH | | OSHA | | |
Ingredients	CAS #	%	TLV	STEL	PEL	STEL	VP mm HG
n-BUTYL ACETATE	123-86-4	< 5.	150 ppm	200 ppm	150 ppm	200 ppm	13 @ 68F
ETHYL 3-ETHOXYPROPIONATE	763-69-9	10.	N.E.	N.E.	N.E.	N.E.	.7 @ 68F
		Manufacturer recommends a workplace exposure limit of 50 PPM-TWA; 100 PPM-STEL.					
DISPERSION AID	PROPRIETARY	< 1.	N.E.	N.E.	N.E.	N.E.	
		New Jersey Trade Secret Registry Number: 800963-5040					
XYLENE	1330-20-7	< 1.	100 ppm	150 ppm	100 ppm	150 ppm	5.1 @ 68F
ETHYL BENZENE	100-41-4	< 0.1	100 ppm	125 ppm	100 ppm	125 ppm	7.1 @ 68F
		IARC has determined that ethylbenzene is possibly carcinogenic to humans.					
ISOBUTYL ALCOHOL	78-83-1	< 0.1	50 ppm	N.E.	50 ppm	N.E.	8.8 @ 68F
ANTI-FLOAT AGENT	1317-65-3	< 1.	10 mg/M3	N.E.	10 mg/M3	N.E.	
STRONTIUM CHROMATE	7789-06-2	20.			.1 ppm	N.E.	
		The ACGIH TWA for Strontium Chromate (CAS 7789-06-2) as Cr is 0.0005 mg/m3).					
METHYL ETHYL KETONE	78-93-3	< 5.	200 ppm	300 ppm	200 ppm	300ppm	70 @ 60F
2-4 PENTANEDIONE	123-54-6	< 5.	N.E.	N.E.	N.E.	N.E.	6.9 @ 68F
		Union Carbide recommends a TLV of 20 ppm-TWA.					
DIBUTYLTIN DILAURATE	77-58-7	< 0.1	N.E.	N.E.	.1 mg/M3	.1 mg/M3	.2 @320F
		Causes skin and eye irritation. Harmful if swallowed or absorbed through skin. May cause liver and kidney damage.					

      THE ABOVE LISTED PRODUCTS ARE ON THE TSCA INVENTORY LIST.

N.E. = Not Established

                SECTION   III - PHYSICAL DATA

Boiling Range: 175 - 401 Deg. F   Vapor Density: Heavier than Air.
Evap. Rate: 0.66 x n-Butyl Acetate Liquid Density: Heavier than Water.
Volatiles vol % 28.4   Wgt% 19.0   Wgt per gallon: 11.53 Pounds.
                                       Spec. Gravity: 1.38415

Appearance: BROWN LIQUID WITH SOLVENT ODOR
        V.O.C.: 262 G/L
SOLUBILITY IN WATER: Insoluble   PH: Not applicable
AUTOIGNITION TEMPERATURE: No information found
DECOMPOSITION TEMPERATURE: No information found
CORROSION RATE: No information found
VISCOSITY: This liquid to heavy viscous material

                SECTION   IV - FIRE AND EXPLOSION HAZARD DATA

Flammability Class: IB   Flash Point:23 F TCC LEL: 1.00% UEL: 11.40%
-EXTINGUISHING MEDIA:
    FOAM, ALCOHOL FOAM, CO2, DRY CHEMICAL, WATER FOG
-SPECIAL FIREFIGHTING PROCEDURES:
    Full fire fighting equipment with self-contained breathing
    apparatus and full protective clothing should be worn by fire
    fighters. Water may be used to cool closed containers to prevent
    pressure build-up, auto ignition or explosion.
-UNUSUAL FIRE & EXPLOSION HAZARDS:
    Keep containers tightly closed. Isolate from heat, sparks,
    electrical equipment and open flame. Closed containers may
    explode when exposed to extreme heat. Application to hot
    surfaces requires special precautions. During emergency
    conditions overexposure to decomposition products may cause a
    health hazard. Symptoms may not be immediately apparent.

                SECTION   V - HEALTH HAZARD DATA

-PERMISSIBLE EXPOSURE LEVEL:
    SEE SECTION II, HAZARDOUS INGREDIENTS.
-EFFECTS OF OVEREXPOSURE:
    INHALATION: Irritation of the respiratory tract & acute nervous
    system depression characterized by the following progressive
    steps: headache, dizziness, staggering gait, confusion,
    unconsciousness or coma.

MATERIAL SAFETY DATA SHEET   Printed : 07/19/01
For Coatings, Resins and Related Materials
                                      Revised : 06/30/99

SECTION   I - PRODUCT IDENTIFICATION

Manufacturer: DEFT, INC. (CAGE CODE 33461)   Information Phone: (949) 474-0400
             17451 VON KARMAN AVENUE   Emergency Phone: (800) 424-9300
                                               CHEMTREC   Phone: 800-424-9300
             IRVINE   CA
             92614

Product Class: ALIPHATIC ISOCYANATE | Hazard Ratings: Health - 4
Trade Name   : CAT,TT-P-2760A,TYP 1,CL C | none -> extreme   Fire - 3
Product Code : 03Y002CAT | 0 ---> 4   Reactivity - 1
C.A.S. Number: NONE |

SECTION II - HAZARDOUS INGREDIENTS

| | | | | --------- Exposure Limits --------- | | |
| | | | ACGIH | | OSHA | | VP |
Ingredients	CAS #	Weight %	TLV	STEL	PEL	STEL	mm HG
POLYMERIC HEXAMETHYLENE DIISOCYANATE	28182-81-2	55.	N.E.	N.E.	N.E.	N.E.	
	822-06-0						

HEXAMETHYLENE DIISOCYANATE (HDI) CAS NO. 822-06-0, free monomer
content averages 0.10% based on resin solids at the time of
manufacture. However, after 12 months storage, the free monomer
content may rise to a maximum of 0.14%. The ACGIH has a TLV
of 0.005 ppm TWA.

METHYL ISOBUTYL KETONE	108-10-1	20.	50 ppm	75 ppm	50 ppm	75 ppm	15 @ 68F
n-BUTYL ACETATE	123-86-4	< 5.	150 ppm	200 ppm	150 ppm	200 ppm	13 @ 68F
METHYL ETHYL KETONE	78-93-3	20.	200 ppm	300 ppm	200 ppm	300ppm	70 @ 68F

THE ABOVE LISTED INGREDIENTS ARE ON THE TSCA INVENTORY LIST,ALSO
ANY UNLISTED INGREDIENTS.

N.E. = Not Established

SECTION III - PHYSICAL DATA

Boiling Range: 175 - 460 Deg. F   Vapor Density: Heavier than Air.
Evap. Rate: 2.92 x n-Butyl Acetate Liquid Density: Lighter than Water.
Volatiles vol % 51.5   Wgt% 63.5   Wgt per gallon: 7.98 Pounds.
                                        Spec. Gravity: 0.95798
Appearance: AMBER LIQUID WITH SOLVENT ODOR
    V.O.C.: 420 G/L
SOLUBILITY IN WATER: Insoluble   PH: Not applicable
AUTOIGNITION TEMPERATURE: No information found
DECOMPOSITION TEMPERATURE: No information found
CORROSION RATE: No information found
VISCOSITY: Thin liquid to heavy viscous material

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flammability Class: IB   Flash Point:23 F TCC LEL: 1.20% UEL: 11.00%
-EXTINGUISHING MEDIA:
    FOAM, ALCOHOL FOAM, CO2, DRY CHEMICAL, WATER FOG, WATER SPRAY
-SPECIAL FIREFIGHTING PROCEDURES:
    Full fire fighting equipment with self-contained breathing
    apparatus and full protective clothing should be worn by fire
    fighters. Water may be used to cool closed containers to prevent
    pressure build-up, auto ignition or explosion. During a fire HDI
    vapors and other irritating vapors may be generated by
    combustion or thermal decomposition.
-UNUSUAL FIRE & EXPLOSION HAZARDS:
    Keep containers tightly closed. Isolate from heat, sparks,
    electrical equipment and open flame. Closed containers may
    explode when exposed to extreme heat. Application to hot
    surfaces requires special precautions. During emergency
    conditions overexposure to decomposition products may cause a
    health hazard. Symptoms may not be immediately apparent.

SECTION   V - HEALTH HAZARD DATA

-PERMISSIBLE EXPOSURE LEVEL:
    SEE SECTION II, HAZARDOUS INGREDIENTS.
-EFFECTS OF OVEREXPOSURE:
    INHALATION: Irritation of the respiratory tract & acute nervous
    system depression characterized by the following progressive
    steps: headache, dizziness, staggering gait, confusion,
    unconsciousness or coma.
    SKIN AND EYE CONTACT: SKIN: Isocyanates react with skin protein
    and moisture and can cause irritation. Symptoms may be swelling,
    redness, and rash.
    EYES: Liquid, aerosols, or vapors are irritating and may cause
    tearing, redness, and swelling accompanied by a stinging
    sensation.
    SKIN ABSORPTION: Prolonged or repeated contact can cause
    moderate irritation, drying, and defatting of the skin which can

Solvent-Based Epoxy-Polyamide Primer Paint
(MIL-P-23377G, Type I, Class C)

Large Particle-Size Range Impactor (Mass Cr^{6+} per Mass Dry Paint) x 100%							
Stage:	1	2	3	4	5	6	7
	9.63%	4.42%	5.32%	7.69%	6.44%	3.94%	2.45%
	7.99%	4.38%	4.94%	7.70%	6.34%	4.04%	ND
	5.61%	4.01%	4.24%	7.08%	ND	3.90%	2.42%
	ND	ND	ND	ND	6.70%	5.65%	3.20%
	8.35%	ND	ND	8.55%	ND	7.65%	4.22%
	ND	2.33%	5.96%	ND	ND		ND
	5.48%	5.00%	5.44%	5.94%	5.54%	3.77%	2.30%
	4.58%	6.54%	5.14%	6.28%	5.83%	4.42%	2.84%
Mean %Cr:	6.94%	4.45%	5.17%	7.20%	6.17%	4.77%	2.90%
n =	6	6	6	6	5	7	6
std dev =	1.99%	1.37%	0.57%	0.98%	0.47%	1.42%	0.73%

Small Particle-Size Range Impactor (Mass Cr^{6+} per Mass Dry Paint) x 100%							
Stage:	1	2	3	4	5	6	7
		6.33%	ND	2.79%	1.50%	0.83%	0.68%
		5.56%	4.13%	2.66%	1.82%	1.27%	0.89%
		7.21%	ND	1.20%	1.19%	0.84%	0.75%
		4.92%	2.61%	1.77%	0.81%	0.51%	ND
		8.71%	6.83%	3.66%	2.61%	1.44%	0.98%
		8.71%	ND	2.46%	2.52%	1.69%	1.42%
		9.30%	4.40%	2.67%	1.24%	1.25%	0.93%
		5.97%	4.07%	2.67%	2.25%	1.64%	1.29%
Mean %Cr:		7.09%	4.41%	2.48%	1.74%	1.18%	0.99%
n =		8	5	8	8	8	7
std dev =		1.65%	1.53%	0.73%	0.67%	0.42%	0.27%

Note: ND denotes data was collected, but lost before analysis was complete

Large Particle-Size Range Impactor (Mass Cr^{6+} per Mass Dry Paint) x 100%							
Stage:	1	2	3	4	5	6	7
	ND	5.35%	5.96%	8.78%	8.36%	5.10%	1.79%
	5.60%	4.51%	5.04%	6.46%	6.64%	4.07%	1.29%
	5.69%	6.71%	6.65%	6.23%	ND	5.01%	1.80%
	6.05%	ND	6.39%	6.34%	6.31%	4.52%	2.63%
	6.44%	5.43%	5.99%	5.18%	5.42%	ND	2.21%
	4.43%	4.83%	4.93%	5.95%	6.65%	5.03%	2.27%
	7.27%	ND	ND	6.78%	7.00%	4.54%	2.53%
	5.70%	4.73%	5.30%	ND	6.22%	5.15%	0.55%
	4.98%	5.19%	ND	ND	5.61%	3.85%	1.27%
	4.68%	3.30%	4.35%	6.07%	5.44%	3.54%	1.74%
	4.89%	5.30%	ND	6.45%	6.83%	ND	1.50%
	7.34%	5.57%	7.36%	5.48%	5.83%	4.21%	1.33%
	5.61%	8.23%	8.10%	5.47%	5.97%	7.17%	2.74%
	8.61%	6.16%	8.29%	9.46%	9.58%	6.89%	3.05%
	5.01%	7.20%	7.04%	5.89%	5.42%	4.69%	1.72%
	8.19%	5.41%	6.12%	8.87%	6.19%	5.55%	1.83%
mean %Cr:	6.03%	5.57%	6.27%	6.67%	6.50%	4.95%	1.89%
n =	15	14	13	14	15	14	16
std dev =	1.29%	1.22%	1.21%	1.36%	1.15%	1.04%	0.65%
Small Particle-Size Range Impactor (Mass Cr^{6+} per Mass Dry Paint) x 100%							
Stage:	1	2	3	4	5	6	7
		9.07%	5.82%	2.62%	1.08%	0.70%	0.50%
		7.99%	5.38%	2.14%	0.87%	0.64%	0.62%
		8.74%	6.15%	2.46%	1.05%	1.19%	1.17%
		8.56%	5.16%	3.54%	1.60%	1.14%	ND
		5.68%	ND	2.49%	0.81%	0.54%	0.51%
		7.35%	4.43%	2.41%	0.95%	0.25%	1.17%
		6.36%	6.01%	2.83%	1.20%	0.92%	0.81%
		6.96%	5.36%	2.86%	1.12%	1.07%	1.00%
		5.37%	ND	1.93%	0.74%	0.92%	0.49%
		5.59%	4.24%	1.87%	1.00%	0.59%	0.48%
		5.48%	4.65%	3.32%	1.24%	0.52%	0.42%
		5.80%	4.64%	3.19%	1.23%	0.57%	ND
		5.46%	4.28%	4.00%	1.59%	0.66%	0.56%
		5.71%	4.61%	4.16%	1.78%	ND	0.67%
		4.97%	4.22%	3.40%	1.06%	0.54%	0.39%
		5.93%	4.65%	3.02%	0.99%	0.53%	0.57%
mean %Cr:		6.56%	4.97%	2.89%	1.15%	0.72%	0.67%
n =		16	14	16	16	15	14
std dev =		1.36%	0.67%	0.68%	0.29%	0.27%	0.27%

APPENDIX E-3: Raw Data Table for
Solvent-Based Elastomeric, Polyurethane Primer Paint
(TT-P-2760A, Type I, Class C)

Large Particle-Size Range Impactor (Mass Cr^{6+} per Mass Dry Paint) x 100%							
Stage:	1	2	3	4	5	6	7
	3.80%	2.77%	3.30%	2.98%	2.82%	ND	ND
	3.31%	1.91%	2.66%	3.15%	2.67%	1.91%	0.93%
	4.66%	4.31%	4.62%	ND	4.66%	2.99%	1.57%
	4.66%	3.92%	ND	4.25%	4.14%	3.25%	1.54%
	4.47%	3.94%	4.06%	3.86%	3.97%	2.60%	1.22%
	4.20%	1.80%	3.90%	4.18%	3.66%	2.63%	1.25%
	4.77%	4.59%	4.17%	4.83%	4.85%	3.03%	1.57%
	ND	4.52%	4.09%	4.54%	4.29%	3.16%	1.49%
	4.87%	4.44%	4.46%	4.13%	4.56%	1.13%	4.17%
	4.31%	3.83%	2.61%	2.87%	2.08%	1.89%	1.58%
average %Cr:	4.34%	3.60%	3.76%	3.86%	3.77%	2.51%	1.70%
n =	9	10	9	9	10	9	9
std dev =	0.51%	1.06%	0.74%	0.71%	0.94%	0.72%	0.95%

Small Particle-Size Range Impactor (Mass Cr^{6+} per Mass Dry Paint) x 100%							
Stage:	1	2	3	4	5	6	7
		3.30%	2.26%	1.57%	0.92%	0.43%	0.29%
		3.14%	2.12%	1.23%	0.83%	0.48%	0.32%
		3.70%	2.74%	1.59%	1.01%	0.56%	0.28%
		3.35%	2.73%	1.70%	0.93%	0.61%	0.42%
		3.89%	3.42%	1.80%	0.83%	0.43%	0.27%
		4.72%	2.63%	1.68%	0.60%	0.50%	0.35%
		2.33%	2.98%	1.66%	1.00%	0.45%	0.27%
		4.22%	3.02%	1.74%	0.94%	0.65%	0.70%
		4.24%	2.99%	1.70%	1.02%	0.51%	0.29%
		4.28%	2.98%	1.82%	0.92%	0.52%	0.36%
average %Cr:		3.72%	2.79%	1.65%	0.90%	0.51%	0.36%
n =		10	10	10	10	10	10
std dev =		0.70%	0.39%	0.17%	0.13%	0.08%	0.13%

Note: ND denotes data was collected, but lost before analysis was complete

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Vita

Captain Brian S. Rhodes graduated from Pace High School in Pace, Florida in June 1990. He entered undergraduate studies at the University of Florida where he graduated with a Bachelor of Science degree in Environmental Engineering Sciences in December 1994. He was commissioned as a Second Lieutenant through the Officer Training School at Maxwell AFB, Alabama in February 1998.

His first assignment was to the 37th Civil Engineer Squadron, Lackland AFB, Texas, where he served in a variety of capacities. After working as a program manager in the Environmental Flight, he served as the Engineering Advisor in the 37th Training Wing Competitive Sourcing Office. After returning to the Civil Engineer Squadron, he assumed the interim role of Chief of the Privatization Flight, where he was responsible for the oversight of the Department of Defense's first housing privatization initiative. In August 2000, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation he will remain at AFIT where he will serve as an instructor at the Civil Engineering and Services School.

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	5b. GRANT NUMBER
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7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 P Street, Building 640 WPAFB OH 45433-7765	8. PERFORMING ORGANIZATION REPORT NUMBER AFIT/GEE/ENV/02M-11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) HQ AFMC/CEVQ AFRL/MLQL Attn: Lt Col Michael Boucher Attn: Mr. Thomas Naguy 4225 Logistics Ave, Rm A128 2179 12th Street, Bldg 652, Rm 122 WPAFB OH 45433-7765 WPAFB, OH 45433-7718 (937) 257-4680 (937) 986-5709	10. SPONSOR/MONITOR'S ACRONYM(S) HQ AFMC/CEVQ, AFRL/MLQL
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12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The United States Air Force relies on the corrosion inhibiting properties of chromate-containing primer paints to protect the aluminum skin of its aircraft. Hexavalent chromium (Cr^{6+})—the ingredient responsible for the corrosion inhibiting characteristics of these primers—is a known human carcinogen. The concentration of Cr^{6+} in different particle sizes of paint overspray is important to understand health implications to painters as well as filtration efficiency.

This research explores the possibility of a particle size bias in the Cr^{6+} content of three commonly used aircraft primers: solvent-based epoxy-polyamide (MIL-P-2377G), water-based epoxy-polyamide (MIL-PRF-85582C), and solvent-based polyurethane (TT-P-2760A). Seven-stage cascade impactors collected overspray particles into distinct bins with particle size cutoff diameters ranging from 0.7 μm to 34.1 μm. The mass of the dry paint collected in each bin was determined and analyzed for Cr^{6+} with an Atomic Absorption Spectrometer.

In all three primers, smaller particles contained disproportionately less Cr^{6+} per mass of dry paint than larger particles. Particles with an aerodynamic diameter under 7 μm contained less Cr^{6+} per mass of dry paint as the particles became smaller. Particles less than 2.6 μm have a mean Cr^{6+} content of approximately one-third of the expected value.

15. SUBJECT TERMS

Primer, overspray, chromate, chromium, chrome, particle size, lung deposition, aerospace coatings

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